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University of Massachusetts Amherst

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The Effects of Domestic Refrigeration on Foods

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THE EFFECTS OF DOMESTIC REFRIGERATION

ON FOODS

John E. W. McConnell

Thesis Submitted for the Degree
of
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INTRODUCTION

The use of refrigeration for the preservation of foods has been known and practiced by man since the beginning of history. Food was often stored in caves, in containers immersed in flowing water, or in deep wells, where the temperature was 50-60°F. even in warm weather. In hot climates water was kept comparatively cool by storing it in porous jars so that the evaporation of the water on the sides of the vessel cooled the contents.

More recently man learned to store ice, cut in the winter, for use throughout the summer months. The first ice box in America was set up in 1802, according to Moyer and Fittz (1932). However, only in very recent times has mechanical refrigeration been introduced with its accurate control over the storage temperature.

The importance of proper refrigeration can be appreciated when it is known that in 1929 an estimated four percent of the income of the average American home was wasted due to food spoilage, which could have been prevented by proper refrigeration. (Frigidaire Corp., 1929).

According to this same publication, the first mechanical ice-making machine was invented by Dr. William Cullen in England in 1775, while the forerunner of the modern mechanical refrigerator was invented in 1834 by

Jacob Perkins, a Massachusetts engineer, who used ether as the refrigerant. The first commercial use of the invention was in 1855, when it was used to freeze ice, which in turn was used to refrigerate food. The automatic mechanical household refrigerator was first introduced about 1910. Since 1920 the adoption of these devices in homes has been so rapid that today there are over ten million units in use in the United States.

There are two types of domestic refrigerators on the market at the present time. One maintains a relatively low humidity with considerable air circulation, while the more recent type has very slight air circulation and a higher humidity. Naturally there are conflicting claims as to the advantages of each type of refrigerator.

The manufacturers first concentrated on perfecting the mechanism of their products and only recently have they turned their attention to improvement of the actual storage conditions.

Most work in refrigeration has been done to safeguard the quality of foods during transportation, manufacture, commercial storage or distribution. The major part of this work has been in the frozen food field where the holding temperature is around 0°F., and in cold storage where storage is for long periods of time. However, very little research has been conducted on the storage of foods in domestic refrigerators which run at a temperature of approximately 40°F. It would seem that this phase is of equal importance, as ordinarily much of our food is not used immediately after purchasing, but is stored until needed or as left-overs.

It is generally assumed that the act of placing food in a refrigerator preserves its nutritive value besides slowing up microbial growth. However, 40°F. is a relatively high temperature and it would seem possible that much enzymatic activity would still go on at this temperature. Therefore, it is probable that we are receiving much less nutritive value from foods stored in a refrigerator than was present at first.

This investigation was carried out in an attempt to gather information on the effects of refrigeration on the nutritive value and keeping quality of various foods under normal household conditions, and the factors, especially humidity, which affect the nutritive value of foods.

Different methods of defrosting frozen foods were studied, as well as the effect of storage temperature on their quality. The effect of humidity, air current, and type of containers on odor and taste transfer was also investigated.

The work was divided into several parts, which included the following:

1. Operation of a refrigerator.
2. The storage of eggs.
3. The storage and defrosting of quick-frozen foods.
4. The storage of left-over foods.
5. A study of odor and taste transfer.

REVIEW OF LITERATURE

A review of the literature reveals that comparatively little work has actually been done on the domestic refrigeration of foods. However, a considerable amount of research has been carried on in the study of commercial cold storage conditions and frozen foods. Some of these studies have been on the storage of foods at or near 40°F., the normal temperature of the household refrigerator.

In recent years interest in the effect of domestic refrigeration on foods has been aroused, chiefly because of the introduction of a new high humidity type of refrigerator, and because of the public's increased interest in nutrition.

From an extensive survey of the literature on the use of refrigeration in the home, it may be concluded that home refrigeration is very effective in the preservation of vitamins A and C. Temperatures of 40°F. or lower should be maintained together with a high humidity for most foods. Good foods if properly refrigerated in the home will not cause food poisoning. Refrigeration is an aid to health not only because it retards food spoilage but also because it retains vitamins, thus helping us to obtain an adequate diet.

Domestic Refrigeration

According to Tanner (1932) cold is the most satisfactory agent for the preservation of food for short periods, the electric refrigerator being preferable because a constant temperature can be maintained. The effects of bacteria are merely inhibited by refrigeration as microorganisms may slowly reproduce and change food, even at low temperatures.

Ackerman (1929) in comparing the efficiency of an electric refrigerator with that of an ice box reported that the operating cost of an electric refrigerator per year was 50 percent less than the cost of using ice. Mechanical refrigeration was much superior in all respects to refrigeration by means of ice.

The volatile products given off by foods in an ice refrigerator were found by Vauclin (1936) to be absorbed by the melting ice and eventually caused foul odors.

Chenoweth (1937) reported no appreciable difference in the bacterial count of the air of ice or mechanical refrigerators. Effects of covering or wrapping foods on the shrinkage, bacterial growth and flavor of fruits, vegetables, meat and dairy products were also studied.

Fellers (1942) stated that a temperature of 48°F. is far less effective in delaying spoilage than one of 40-41°F. At the latter temperatures food-poisoning bacteria grow little or not at all; hence there is no danger of food spoilage from sound food stored a few days. Under household conditions, Edmonson, Thom and Giltner (1923) found that food experimentally inoculated with Bacillus botulinum and held in an efficient ice box for one or two days showed practically no development of the organism, and was perfectly safe on ordinary cooking.

Food poisoning strains of staphylococci were found by Jones and Lochhead (1936) to develop rapidly in vegetables held at room temperature. However, at 40°F. in an electric refrigerator no multiplication was observed during short storage periods.

Crooks and Ritchie (1938) in investigating the storage of haddock found that frozen fish could be stored two to eight days in the freezing compartment of an electric refrigerator without spoilage. When fresh fish was kept in the cabinet itself at 40°F. spoilage set in in 14 days as compared to 7 days when stored in an ice refrigerator. At room temperature the fish spoiled within two days.

The effects of discontinuous refrigeration on the growth of bacteria was studied by Prescott, Bates and Needle (1931). Spoilage was most rapid in covered foods which were removed from the refrigerator and allowed to stand at room temperature for short periods of time and then replaced. In some cases growth increased rapidly, even at comparatively low temperatures, when the storage was discontinuous.

The storage of meat in small refrigerators was investigated by Haines and Smith (1932) (1933) with special emphasis on the effect of temperature on the growth of microorganisms. Pennington, Hepburn, St. John and Whitmer (1913) found that the changes in the chemical composition, bacterial content and histological structure of the flesh of fowls, stored in a home refrigerator at 45-55°F. for five days, was equivalent to the changes taking place in only two days at room temperature.

Carlsson (1927) compared the changes taking place in food during storage in an ice and an electric refrigerator and found the latter much more efficient because of its lower temperature and humidity. Winter, Alderman and Waite (1935) stated that berries could be preserved several days in either an ice box or a mechanical refrigerator.

Operating Conditions

Sater (1938) found that the power consumption of a refrigerator was more dependent on the length of time the door was open than on the actual number of door openings made.

According to Fellers (1942) the most effective and economical operating temperature for a domestic refrigerator is between 38° and 43°F. with an average of 40-41°F.

Denner (1933) found temperatures of 40-45°F. best and most efficient for home refrigeration. Milk and pork chops should be stored below 45°F., but 35°F. was too expensive. Lettuce, cabbage and cooked apples should never be stored open in a refrigerator but should be covered. Meat, however, was found to keep better when it was not stored in air-tight containers. It was recommended that foods be cooled to approximate room temperature before placing in the refrigerator.

Lanman (1931) found that temperatures of less than 45°F. were necessary for the successful storage of meat and milk. Lettuce became slightly wilted in four or five days at this temperature but was still edible.

Erbeck (1940) recommended storage temperatures between 40° and 50°F. for such foods as milk, butter, eggs, poultry, meat and vegetables. Refrigeration was found advisable for honey by Wilson and Marvin (1931), even though storage at room temperatures is reasonably safe.

Frozen foods can be kept several days in the freezing compartment of an electric refrigerator, according to Tressler and DuBois (1940), but after thawing should not be stored longer than 24 hours.

Hull (1927) discussed household refrigeration with special emphasis on the proper operating temperature. He advocated temperatures of less than 45°F. to retard growth of microorganisms. Pabst (1931) also recommended temperatures of less than 45°F. as being necessary for the storage of meat in the home for four days. He found that the growth of bacteria was much more rapid in closed containers than in open ones. Prescott (1932) confirmed the necessity of maintaining this temperature.

Peet (1937) investigated the storage of meat in the home and found fresh meat kept better for short periods of time if wrapped in waxed paper. Cooked meats were found to keep best if wrapped or covered with a perforated cover. However, for long storage periods they should be left uncovered at 45°F. or less.

Procter and Greenlie (1938) studied the optimum conditions for domestic refrigeration of foods and found that the best conditions of storage were temperatures of 40°F. or lower, a high humidity and a relatively low air movement. They also reported a better retention of vitamin C in spinach when stored at refrigerator temperatures, than at room temperatures.

Sharp (1937), on the other hand, stated that as long as there is appreciable air movement the rate of evaporation is independant of the air velocity providing it is not excessive. This confirms the findings of Smith (1930) who stated that at rates between 8 and 18 centimeters per minute the rate of air movement had no effect on the evaporation of moisture from eggs at 32°F. and 30 percent relative humidity.

Loss of Vitamins

The effect of reduced evaporation or, in other words, the effect of humidity on the vitamin content of foods has recently been investigated. Harris, Wissmann and Greenlie (1940) found the loss of vitamin C to be inversely proportional to the relative humidity in the case of many fresh vegetables. The vitamin A (carotene) content of lettuce and carrots was found to depend upon the humidity, but this was not true in the case of fresh spinach, tomatoes and Swiss chard. The destruction of vitamin B_1 was inversely proportional to the humidity.

Harris and Mosher (1941) found the loss of provitamin A in lettuce to be proportional to the dehydration until 40 percent of the moisture had disappeared, after which the destruction became accelerated.

Ihuzi (1940) investigated the storage of grated radishes in a refrigerator and found a better retention of vitamin C at the lower storage temperatures. However, it disappeared quickly at all temperatures except when the vegetable was frozen.

Flavor Transfer

An extensive investigation into the effect of humidity and air movement in a domestic refrigerator on flavor transfer was made by Crocker (1941). Using both foods and chemicals he found that the loss of odor and flavor was directly proportional to the evaporation of moisture from the parent substance; that is, the transfer of the flavor-producing substances was due to a low temperature steam distillation.

The flavor transfer at constant temperatures was proportional to the time, air movement, amount of exposed surface, aridity, and foods themselves. It was claimed that a minimum amount of flavor transfer occurred in ordinary foods when stored in uncovered dishes in a high humidity atmosphere with a low air movement. Ordinary glass-covered refrigerator containers were found to reduce the loss of odor and its pickup by about 50 percent but complete protection in the case of such products as cottage or cream cheese could only be accomplished by screw-top jars or wrapping in tinfoil.

<u>New Uses of the Domestic Refrigerator</u>

The feasibility of storing foods not ordinarily placed in a refrigerator has recently received considerable attention. Coffee has been found to keep its flavor better under refrigeration. (Anonymous, 1942). Landaal-Kaster (1936) discovered that bread could be kept fresh for several days by refrigeration and wrapping. Fellers (1942) stated that wrapped bakers' bread did not become stale and moldy for relatively long periods of time if stored in a refrigerator.

Storage of Foods at Domestic Refrigerator Temperatures

Optimum Conditions of Refrigeration

As stated previously, 40°F. has been found to be the optimum temperature, both economically and practically, for household refrigerators. The optimum conditions of temperature and humidity for cold storage of a wide range of foods have been determined by different investigators. However, for the short storage periods used in domestic refrigeration, available temperatures of approximately 40° and 25°F. and relative humidities of around 65 percent and near 100 percent have proven quite adequate.

As discussed above, high relative humidities have been reported as best for preserving the quality and the vitamin A and C content of various foods. The ordinary refrigerator usually runs at around 60 percent relative humidity. However, more desirable conditions can be obtained by the use of covered dishes or the built-in covered containers, usually called hydrators or vegetable compartments.

Bates and Highlands (1934) stated that in the refrigeration of foods many factors must be considered, amongst which are microbial infection, temperature, relative humidity, velocity of air, and reaction of food with air. Williams (1934) determined the optimal conditions of temperature and humidity and methods of handling for many kinds of fresh vegetables.

Tavernetti (1933) recommended a holding temperature of 40-45°F. for general storage. Meat should be kept in the coldest part of the refrigerator, not covered or wrapped. Vegetables kept best in the hydrators or other closed containers. Due to absorption of odors milk and butter should preferably be kept in covered dishes, while other odor absorbing foods, such as meat and eggs, should be kept as far away from odorous foods as possible. Onions, lemons, cantaloupes and cabbage are particularly bad offenders as far as odor is concerned.

Even at temperatures as low as -25°F. certain chemical reactions have been found to take place according to Tressler and DuBois (1940). However, Fellers (1942) stated that there is no danger from spoilage, food poisoning or appreciable vitamin losses in foods kept at 40°F. Maintenance of a constant temperature was found to be very important by Rose, Wright and Whiteman (1941). Variations of more than ±2° caused a condensation of moisture which favors mold growth and decay.

Drozdov and Drozdov (1936) in their investigations on the storage of meat found less chemical changes occurring at 40°F. than at 60°F. The ripening of pears ceases at 43°F. according to Magness, Diehl and Allen (1927). Therefore the green fruit should not be stored in the refrigerator. The storage time was found to be doubled for every drop of approximately 10° between 53° and 36°F.

Bananas should not be refrigerated, according to Rose, Wright and Whiteman (1941). Not only are they notorious contaminants of other foods, as far as odor and taste go, but below 56°F. they suffer an injury known as chilling or peel injury, which is characterized by discoloration and susceptibility to injury.

Clifford (1925) noted that beef and mutton remained in their original condition after three days' storage in a refrigerator at 35°F. Fellers and Harvey (1940) found that fresh haddock fillets could be kept satisfactorily for four to five days at 38°F. Defrosted cod fillets were of excellent quality after 24 hours' storage but became stale in five days.

Schweigart, Welch and Kellner (1939) found temperature to be the most important factor in the storage of asparagus. Respiration was reduced by wrapping in cellophane, thereby holding in the evolved carbon dioxide and thus retarding chemical decomposition and loss of weight. Baker (1938) reported that a high relative humidity kept pecans in excellent condition.

Harris, Wissmann and Greenlie (1940) reported that the rate of evaporation from fresh leafy vegetables and legumes was proportional to the humidity and air movement. High humidities prevented wilting plasmolysis which accelerates oxidation of the cell constituents and makes the substances more susceptible to microbial invasion.

Allen and Pentzer (1935-B) found that high relative humidities prevented dehydration during storage but might allow rapid mold growth on some fruits, grapes being especially susceptible.

Hirsch (1930) stated that in order to keep products properly, the difference between the vapor tension of the product and the vapor pressure of the atmosphere should be small, otherwise desiccation or condensation will occur. It is preferable to maintain the vapor pressure of the atmosphere slightly lower than that of the product. In the storage of eggs, three to five percent difference gave good results while a greater difference could be maintained if the atmosphere was not circulated.

Walter (1925) found that organic substances do not become moldy when the relative vapor pressure is below 80 percent at their surface. The minimum humidity necessary for the growth of mold fungi and bacteria was 85 and 95 percent respectively.

High humidity storage has been found especially desirable for cucumbers and pepper fruits. (U. S. Dept. Agr., 1939). The optimum humidity for most vegetables at refrigerator temperatures is 85 percent according to Williams (1934). Wrapping vegetables in paper or cellophane appreciably prolonged their possible storage life.

Fellers (1942) recommended covering foods to prevent flavor transfer and dehydration as there is always some air circulation. However, according to Tressler and DuBois (1940) some air circulation is necessary to maintain uniform temperatures.

Allen and Pentzer (1935-A) found that if the rate of air movement was doubled the amount of moisture loss from fruits was increased 33 percent and was equivalent to a drop of about five percent in relative humidity. With humidities up to 40 percent the loss of weight was found to be fairly constant; at higher humidities the loss decreased in proportion to the increase in humidity. On the other hand Smith (1930) stated that an air movement between 8 and 18 centimeters per minute at constant humidity has no effect on the dehydration of eggs. If there is any appreciable air movement it is sufficient to sweep away the saturated atmosphere immediately surrounding the product.

Egg Storage

Due to the consumer's concern over the freshness of eggs, much attention has been given to their handling and proper care. However, practically all the research on the storage of eggs has been done in the cold storage field, that is, storage at temperatures around 32°F. for relatively long periods of time.

According to Sharp (1937) the successful preservation of hens' eggs depends on the following factors:

1. Quality of the eggs placed in storage.
2. Sterility of egg contents.
3. Prevention of luxuriant growth of micro-organisms on shell.
4. Prevention of evaporation.
5. Prevention of absorption of flavors.
6. Temperature.

Baetsle (1935) found that refrigeration was the best method for the preservation of eggs. Tressler (1935) reported more desiccation occurred at high temperatures than at cold storage temperatures.

Sharp and Powell (1930) investigated the effect of temperature on the quality of eggs during storage and found that eggs could be stored at 45°F. for 65 days with the same loss in quality as when stored 8 days at room temperature. Davies (1936) noted that the palatability of eggs, judged by their flavor and texture, decreased rapidly at room temperature and 80 percent humidity. A definite storage flavor was detected in 9 to 15 days under these conditions.

Mullmann and Michael (1940) studied the development of mold on cold storage eggs and found that the growth of mold mycelia on the egg surfaces could be prevented by eliminating moisture from these surfaces. An 85 to 88 percent relative humidity was necessary to maintain such conditions. This caused a considerable loss of moisture but higher humidities, such as 96 percent and above, which reduced this loss, resulted in mold growth after four months.

The recommended relative humidity for cold storage eggs at the present time, according to Heitz (1940), is 86 percent, a compromise to prevent both mold growth and excessive dehydration. This value is based on work done by such men as Smith (1930) who found the loss of moisture from eggs was zero at 100 percent relative humidity but that severe mold growth occurred in 18 days, at this high humidity. At 41°F., the first evidence of mold occurred in nine days. Even at 90 percent relative humidity, Smith found mold appearing in 12 days at this temperature. Sharp (1937) also reported mold growth at relative humidities of 96 percent and higher.

Pennington and Horne (1924) found a close relationship between the relative humidity and the loss of moisture of eggs and that no mold growth occurred on refrigeration at 84 percent humidity even in five months. Moran and Piqué (1926) made similar findings and recommended a relative humidity of 80 percent.

Effects of Refrigeration on the Nutritive Values of Fresh and Cooked Foods

Fellers (1942) in reviewing the effects of refrigeration on the vitamin content of foods stated that a good household refrigerator is very effective in preventing vitamin losses during storage. Some of these reported losses are recorded in Tables 1 and 2.

Vitamin A

From Table 1 it may be seen that vitamin A or carotene is lost during the storage of lettuce, beef livers and butter and in the case of butter is retained best at low temperatures. Baumann and Steenbock (1933) found that exposure to light, air and high temperature increased the loss of carotene but that temperatures of 41°F. greatly reduced this loss. Fellers (1936) also concluded that little loss of vitamin A occurred in vegetables at low temperatures but that a gradual loss occurred at ordinary room temperatures, the loss being roughly proportional to the temperature. However, the destruction is less rapid than in the case of vitamin C.

Harris and Mosher (1941) in their study of the refrigeration of lettuce found the loss of provitamin A was proportional to the amount of dehydration up to a 40 percent loss of weight, after which an increasing rate of loss occurred. Lettuce became wilted when 30 percent of its moisture was lost so that wilting was considered a good index of loss of vitamin A.

As can be seen from Table 1 the vitamin A of lettuce is retained to a greater extent at high humidities. That is, the loss of vitamin A in lettuce is affected by the amount of evaporation of water and in view of this Harris and Mosher (1941) advocated a high humidity and low

Table 1. Loss of vitamins during storage of fresh and cooked foods

Food	Vitamin	Temperature	Storage time	Relative humidity	Loss	Investigator
		°F.	days	percent	percent	
Butter	A (carotene)	32	2 weeks	--	0	De and Majumdar (1938)
		59	2 weeks	--	22.0	
		98	2 weeks	--	47.0	
Lettuce, fresh	A (carotene)	41	7 days	69	31.0	Harris and Mosher (1941)
		42	7 days	88	18.0	
		46	7 days	96	8.0	
		41	7 days	98	5.0	
Liver, fresh beef	A	46	7 days	--	10.0	Holmes, Tripp and Satterfield (1936)
Orange juice, fresh	A (carotene)	40	1 day	--	0	Fellers (1942)
Asparagus, fresh	C	70	2 days	--	20.0	Fitzgerald and Fellers (1938)
Beans, fresh shelled lima	C	41	4 days	65	35.0	Harris, Wissman and Greenlie (1940)
Beans, shelled lima	C	32	2 days	100	19.0	Tressler, Mack, Jenkins and King (1937)
Beans, fresh in pods (lima)	C	2	2 days	--	10.0	same author
Beans, fresh snap	C	41	3 days	65	30.8	Harris, Wissman and Greenlie (1940)
			7 days	65	50.0	
			3 days	93	24.4	
			7 days	93	32.1	
			3 days	98	28.2	
			7 days	98	35.9	
Beans, fresh snap	C	34-37	1 day	60-70	12.0	Mack, Tapley and King (1939)
			2 days	" "	23.0	
			3 days	" "	31.0	
			6 days	" "	52.0	
		46-50	1 day	" "	24.0	

Table 1 (continued)

Food	Vitamin	Temperature	Storage time	Relative humidity	Loss	Investigator
		°F.	days	percent	percent	
Beans, fresh snap	C	46-50	2	60-70	41.0	Mack, Tapley and King (1939)
			3	" "	52.0	
			6	" "	66.0	
		70-74	1	" "	44.0	
			2	" "	59.0	
			3	" "	65.0	
			6	" "	73.0	
Beans, fresh snap	C	59-68	2	-	30-50	Yaroshenko (1938)
		36	2	-	10-17	
Beans, fresh snap	C	32	1	-	7.0	U.S.Dept.Agric.(1939)
			2	-	19.0	
			6	-	53.0	
		Room T.	1	-	41.0	
			2	-	47.0	
			6	-	78.0	
Beans, Fresh snap	C	70	2	-	25.0	Fitzgerald and Fellers (1938)
Beef	C	32	2	-	10.0	Harris (1938)
		77	2	-	25.0	
Broccoli, fresh	C	Room T.	3	-	35.0	U.S.Dept.Agric.(1939)
		70	2	-	35.5	Fitzgerald and Fellers (1938)
Cabbage, cooked	C	34-37	1	-	25.0	Gould, Tressler and King (1936)
			2	-	50.0	
Cauliflower, fresh	C	59-68	2	-	4.0	Yaroshenko (1938)
		41	15	-	0.	Rudra (1937)
Corn-on-the-cob, fresh	C	65-80	1	-	10.0	Dunker, Fellers and Fitzgerald (1937)
			3	-	20.0	
			4	-	50.0	
		40	1	-	10.0	
			3	-	20.0	
			4	-	50.0	

Table 1. (continued)

Food	Vitamin	Temperature	Storage time	Relative humidity	Loss	Investigator
		°F.	days	percent	percent	
Lettuce, fresh	C	41	1	65	26.5	Harris, Wissmann and Greenlie (1940)
			3	65	55.1	
			7	65	48.0	
			1	93	14.3	
			3	93	36.7	
			7	93	38.7	
			1	98	20.4	
			3	98	22.4	
			7	98	33.7	
Liver, fresh goat	C	41	2	--	0.	Rudra (1937)
			8	--	40.0	
Milk, fresh raw	C	Refrig.	1	--	10.0	King and Tressler (1940)
Milk, market	C	Room T.	1	--	39.5	Zollikofer (1940)
		36	1	--	21.6	
Orange juice, fresh	C	40	1	--	10-15	Fellers (1942)
		Room T.	1	--	40-50	
Parsley leaves, fresh	C	41	4	65	17.4	Harris, Wissmann and Greenlie (1940)
			7	65	31.8	
			4	93	8.0	
			7	93	21.0	
			4	98	3.8	
			7	98	15.4	
Peas, thawed frozen	C	Room T.	½ hr.	--	16.0	Todhunter and Sparling (1938)
			1 hr.	--	27.0	
		40	1	--	25.0	
Peas, Fresh shelled	C	41	5	65	12.9	Harris, Wissmann and Greenlie (1940)
			7	65	36.7	
			5	93	4.5	
			7	93	0.2	
			5	98	1.3	
			7	98	6.8	

Table 1 (continued)

Food	Vitamin	Temperature	Storage time	Relative humidity	Loss	Investigator
		°F.	days	percent	percent	
Peas, fresh shelled	C	59-68	2	--	30-50	Yaroshenko (1938)
		36	2	--	10-17	
Peas, fresh shelled	C	80	1-5 hrs.	--	0.	Fenton and Tressler (1938A)
		40	16 hrs.	--	0.	
Peas, fresh shelled	C	39	9 hrs.	--	0.	Jenkins, Tressler and Fitzgerald (1938)
		80	5 hrs.	--	14.0	
Peas, blanched	C	30	10 hrs.	--	0.	same author
Peas, in pods	C	90	18 hrs.	--	10.0	
		70	18 hrs.	--	0.	
		43	18 hrs.	--	0.	
Peas, fresh shelled	C	70	2	--	9.6	Fitzgerald and Fellers (1938)
Potatoes, boiled	C	40	1	--	20.0	Lyons and Fellers (1939)
Soup, boiled cabbage	C	32	1	--	30.0	Buton (1938)
		59	1	--	60.0	
Spinach, fresh	C	41	1	--	19.0	Rudra (1937)
Spinach, fresh	C	70	2	--	47.0	Fitzgerald and Fellers (1938)
Spinach, fresh	C	41	4½	65	77.4	Harris, Wissmann and Greenlie (1940)
			7	65	82.4	
			4½	93	67.6	
			7	93	58.6	
			4½	98	62.4	
			7	98	66.4	
Spinach, fresh	C	59	2	--	30.5	Yaroshenko (1938)
		59	6	--	95.0	
		36	6	--	20.0	
Spinach, fresh	C	34-37	5	--	4.0	Tressler, Mack and King (1936)
			7	--	14.0	
			17	--	44.0	
		73-79	5	--	47.0	
			7	--	95.0	

Table 1 (continued)

Food	Vitamin	Temperature	Storage time	Relative humidity	Loss	Investigator
		°F.	days	percent	percent	
Tomatoes, whole	C	75-88	1-18	--	0.	Brown and Moser (1941)
		44	1-18	--	0.	
Tomatoes, whole	C	Room T.	10	--	0.	Maclinn and Fellers (1938)
Tomatoes, juice	C	41	20 hrs.	--	11.0	same authors
		41	44 hrs.	--	11.0	
		70	20 hrs.	--	20.0	
		70	44 hrs.	--	30.0	
Tomato juice, canned	C	Room T.	26 hrs.	--	10.0	same authors
Tomato juice, canned						
in tin	C	40	4	--	14.0	Hauck (1938)
in glass	C	40	4	--	25.0	
Tomatoes, canned						
in tin	C	40	4	--	6.0	same author
in glass	C	40	4	--	11.0	

air movement for the maximum preservation of this vitamin during the storage of foods. Fellers (1940) had previously concluded that the drying out and wilting of leafy vegetables caused a decrease in their vitamin A content and recommended cool, moist storage conditions.

Vitamin B_1

Comparatively little work has been done on the study of the loss of vitamin B_1 (thiamin) during the storage of foods.

It is generally thought that vitamin B_1 in foods is quite stable. (Fellers, 1936). According to the findings at the Iowa Agricultural Experiment Station (1927-28) carrots lose no vitamin B_1 at 40-45°F. even when stored 24 weeks. Harris, Proctor and Goldblith (1940) found thiamin was retained unusually well regardless of whether the food was stored at room or refrigerator temperatures. Douglas and Richardson (1930) reported similar results for vitamin B_1 in asparagus. Harris, Wissmann and Greenlie (1940) found that vitamin B_1 was better preserved in lettuce if it was stored at high humidities.

Vitamin C

By far the greatest amount of work conducted on the effect of refrigeration on the vitamins has been done on vitamin C.

As may be seen from Tables 1 and 2, it has been proven conclusively that the vitamin C (ascorbic acid) of most foods is easily destroyed at high temperatures. It should be noted that most of the foods listed are fresh vegetables and show a considerable loss of vitamin C at room temperature but that this loss is greatly reduced on refrigeration, especially at higher humidities.

Fenton (1940) in reviewing the subject of loss of vitamin C in vegetables found that this loss is greatly reduced in all vegetables by refrigerated storage. Larochenko (1938) reported that the storage of vegetables at 59° to 68°F. resulted in high losses of vitamin C. These losses are greatly reduced by storing at 36°F., the reduction in loss being relatively greater for longer storage periods.

In some vegetables, such as fresh corn-on-the-cob, the storage temperature seems to have little influence on the ascorbic acid content. It should be noted, however, that even at comparatively low temperatures the loss of ascorbic acid is considerable, in many cases amounting to 50 percent in only a few days.

Ascorbic acid is most stable in acid solution and it is natural that we find products such as whole tomatoes, cranberries and rhubarb losing little or none of their vitamins at refrigerator temperatures, and even when stored at room temperature. Buton (1938) reported that at any one

Table 2. Effect of short storage periods on the vitamin C content of fresh and cooked foods

Food	Loss at room temperature	Loss at refrigerator temperature	Investigator
Asparagus, fresh	considerable	slight	Wolf (1941)
Beans, fresh snap	considerable	less	Robinson (1940)
Broccoli, fresh	considerable	negligible	Wheeler, Tressler & King (1939)
Cabbage, fresh whole	considerable	slight	Gould, Tressler & King (1936)
Cantaloupe, fresh	considerable	less	Wheeler, Tressler & King(1939)
Cauliflower, fresh	considerable	negligible	Wheeler, Tressler & King(1939)
Corn, canned sweet		negligible	Dunker, Fellers & Fitzgerald (1937)
Cranberries, fresh		negligible	Ishan & Fellers (1933)
Endive, fresh	considerable	less	Wheeler, Tressler &King (1939)
Egg plant, fresh	negligible	negligible	Kirk and Tressler (1941)
Kale, fresh	considerable	less	Wheeler, Tressler & King (1939)
Kohlrabi, fresh	considerable	less	Wheeler, Tressler & King (1939)
Lettuce, fresh	considerable	considerable	Wheeler, Tressler & King (1939)
Milk, pasteurized	considerable	less	Failla (1939)

Table 2. (continued)

Food	Loss at room temperature	Loss at refrigerator temperature	Investigator
Oranges, fresh		less than at room temperature	Robinson (1940)
Orange juice, fresh	much more than at refrigerator temperature		Mack, Fellers, Maclinn & Bean (1936)
Orange juice, fresh		slight	McElroy, Munsell and Stienbarger (1939)
Parsnips, fresh	considerable	less	Wheeler, Tressler & King (1939)
Parsnips, cooked		slight	Mayfield & Richardson (1940)
Paw-paws, fresh		slight	Robinson (1940)
Peas, fresh shelled	considerable	negligible	Jenkins, Tressler & Fitzgerald (1938)
Peas, fresh shelled	considerable	less	Robinson (1940)
Peas, fresh in pod	negligible	negligible	Jenkins, Tressler & Fitzgerald (1938)
Peas, fresh in pod	considerable	negligible	Mack, Tressler & King (1936)
Rhubarb, fresh		no loss in hydrator	Brown, Schulle & Fenton (1941)
Radishes,	rapid	rapid	Ihuzi (1940)
Sauerkraut	slight	considerable	Peterson, Mack and Athawes (1939)
Spinach, fresh	considerable	less	A.M.A. (1937)
Spinach, fresh		less than at room temperature	Procter & Greenlie (1938)
Spinach, New Zealand	considerable	less	Wheeler, Tressler & King (1939)
Tomato juice	negligible	negligible	McElroy, Munsell & Stienbarger (1939)

temperature cooked cabbage soup lost decreasing amounts of vitamin C as the pH was lowered. The vitamin C of rhubarb is also very stable, according to Tressler (1938). Kirk and Tressler (1941) reported that fresh egg plants showed small losses of vitamin C in storage at room or refrigerator temperature, the length of storage being more important than the temperature.

Mack, Fellers, Maclinn and Bean (1936) found that when the juice of acid fruits, such as oranges, was pressed out so the air could come in contact with it, the loss of vitamin C was great at room temperature and appreciable even on refrigeration. Roberts (1937) made similar findings in the case of dairy-type citrus beverages.

On the other hand Tauber (1936) found the vitamin C content of orange, lemon, tangerine and grapefruit juices to be little affected when stored for five hours in a refrigerator or at room temperature.

A study of Table 1 also reveals that the amount of moisture in the storage atmosphere and the length of storage have a marked effect on the destruction of vitamin C. For example, the ascorbic acid is best retained at high humidities while its loss increases rapidly with the length of storage.

The behavior of sauerkraut appears to vary from the general rule of greater destruction of vitamin C at higher temperatures, but Peterson, Mack and Athawes (1939) postulated that the carbon dioxide evolved at the higher temperature protects the vitamin C content from the oxygen of the air.

Gould, Tressler and King (1936) reported a much greater loss of ascorbic acid in cooked cabbage than in the fresh whole vegetable. It should also be noted that the loss of vitamin C from such vegetables as peas and lima beans is much less when they are left in the pods than when they are shelled.

The greater loss of vitamin C by pasteurized milk than that which occurs in raw milk is caused, according to King and Tressler (1940), by the catalytic action due to copper contamination picked up in the pasteurizing process.

Gutherie, Hand and Sharp (1938) found that the loss of vitamin C in milk during refrigeration storage amounted to 50-100 percent, depending upon the length of storage. They also found if the milk was deaerated no appreciable loss occurred during storage for three to seven days. Henderson, Foord and Roodhouse (1940) recommend that milk be placed in the refrigerator at once as they found if milk is exposed to sunlight it loses vitamin C rapidly and also develops an oxidized flavor, even when stored at 40°F.

Feener, Palmer and Fitzgerald (1937) reported that although broccoli and spinach contain more ascorbic acid than most vegetables, they lose it more rapidly than do peas, snap beans or asparagus.

Legumes such as peas, lima beans and snap beans, and mushrooms and asparagus lose their ascorbic acid more readily than most vegetables according to Tressler (1938) and Mack, Tapley and King (1939), but this loss can be reduced by refrigeration. Whole fruits, on the other hand have been found by Harris (1938) to retain their vitamins much better than vegetables, because of their acidity.

Feener, Palmer and Fitzgerald (1937) reported that all vegetables except green beans showed a higher vitamin C content when held in a refrigerator than when held at higher temperatures. Much of the loss of vitamin C in spinach during marketing was found to be due to improper handling, which resulted in a crushing and bruising of the leaves.

The vitamin C of tomatoes was found, by Kraus, Washburn and Hoffman (1937), to decrease during ripening but to increase rapidly during the final softening stage on the vine or in storage. Brown and Moser (1941) also found some evidence of an increase in the vitamin C content of tomatoes on ripening but the evidence was not conclusive. House, Nelson and Haber (1929) reported that both vitamins A and C of tomatoes increased during the ripening period. Clow and Marlatt (1930) confirmed the increase of vitamin C during maturation on the vine.

Maclinn and Fellers (1938), however, reported that the degree of ripeness did not influence the vitamin C content of tomatoes to any extent.

The vitamin C content of bananas increases as they get ripe according to Harris and Poland (1939), but decreases when they get over-ripe. Pau-paus also increase in vitamin C on ripening. (Robinson, 1927).

Miscellaneous

Vitamin D is one of the more stable vitamins and according to Fellers (1936) shows no marked destruction during ordinary domestic storage periods.

Although no work has been done on the effect of storage on the vitamin E content of foods it is known to be quite stable. Fellers (1936) stated that vitamin E is probably not affected under dry cool storage conditions and that vitamin G, also, is not seriously injured.

Emmett and Grindley (1909) found that fresh meats refrigerated for six days were just as nutritious as originally, as far as proteins, minerals, carbohydrates and fats were concerned.

Carbohydrate metabolism was discovered by Appleman and Arthur (1919) to cause a loss of sugar in green sweet corn during storage. The loss of sugar in 24 hours amounted to 8.0, 17.0 and 25.6 percent at 32°, 50° and

68°F. respectively. Cold storage of fresh snap beans on the other hand accelerated the conversion of starch to sugar according to Parker and Stuart (1935).

Kertesz and Green (1932) found that the sugar content of fresh peas decreased when stored for only a few days at 30°F. but remained constant when they had been blanched prior to storage. Fellers (1942) stated that none of the nutrient properties are lost from hard boiled eggs, cheese and meat products when stored for a few days in a refrigerator.

Rancidity of fats and fatty foods is appreciably retarded by low temperatures according to Lea (1939). However, oxidative changes were not entirely prevented. Mitchell (1940) found lard could be stored at 36-40°F. for long periods of time without developing rancidity. This agrees with the findings of Nakonechnyi (1939) who also found the degree of humidity to have a great effect on bacon during storage.

Piqué (1938) stated that fruits and vegetables are killed by freezing and on thawing show considerable chemical and physical changes which, if the foods are not consumed immediately, result in off-flavors and colors.

Frozen meat was found by Brooks (1930) to discolor on the surface even at -4°F. but this was very slight even at 32°F. However, at 50° and 68°F., the discoloration was appreciable in 24 hours. Tressler (1932) stated that frozen foods such as fatty fish, rust or oxidize on long storage. Peaches, cherries, pears, apples, mushrooms and parsnips darken under similar conditions. Jones (1938) noted that frozen cherries and peaches, if allowed to thaw out of their cartons, turned very brown.

Heiss and Hohler (1933) reported that the color changes occurring in chilled meat are due to:- (1) oxidation of hemoglobin to methemoglobin; (2) loss of moisture from the surface together with an increase in the concentration of the colored constituents; and (3) disintegration of the globin components.

The browning of peaches is due to the action of oxidase enzymes on catechol-tannins, according to Kertesz (1934). Woodra (1940) found that lowering the temperature retarded but did not prevent browning. The browning of fresh sliced peaches was found to be negligible when stored at 32-50°F. in a refrigerator for two hours. However, at 26°F. which is below their freezing point they became discolored due to the action of the ice crystals breaking up the cells and freeing their constituents.

The softening of fruits is retarded by low temperatures. Appleman and Conrad (1926) were of the opinion that the softening of peaches was due to the conversion of insoluble protopectin into soluble pectin. The intensity of this reaction was only one quarter as much at 38° as at 65°F.

Pickett (1932) found that the pH value of juices from frozen fruits increased with the storage of the berries at 10°F., due in part to dehydration. A similar increase in acidity of asparagus occurred at higher temperatures. It was also noted that asparagus remained fresh for 11 days at 34°F.

A loss of 1.8 to 7.1 percent of weight was reported by Tookhshnide (1934) in storing beef for 48 hours at 80 to 95 percent relative humidity and approximately 35°F. Mutton lost 2.0 to 2.2 percent of weight in 24 hours and eggs lost 0.8 to 0.9 percent in one month.

Parker and Stuart (1935) observed that snap beans lost 20 percent of their weight at 82°F. and 9 percent at 36°F. when stored for four days. The relative humidities were not recorded, but no doubt they were the determining factors.

Harris and Mosher (1941) stated that the moisture loss of lettuce was proportional to the relative humidity. Lettuce lost 65 percent of its weight in seven days in a refrigerator at 69 percent relative humidity but only eight percent when the humidity was raised to 93 percent.

Effects of Refrigeration on the Nutritive Values of Frozen Foods

A knowledge of the proper conditions for handling frozen foods in the home is becoming more and more important because of their increasing use. Storage temperatures of 0°F. and lower have been shown by many workers to be necessary for the commercial storage of frozen vegetables and meats. Most frozen fruits on the other hand should be stored at 0° to 10°F., according to Joslyn (1934). These low temperatures, however, are not reached in the freezing compartments of present day refrigerators.

At normal operating temperatures the ordinary electric refrigerator keeps frozen foods, stored in the freezing compartment, at about 20° to 25°F. This temperature can be lowered as far as 12°F. or less in some makes, but the refrigerator temperature itself is lowered at the same time to near freezing. This temperature is undesirable as there is great danger of foods being frozen, if stored too near the coils. The cost of operation is also much greater at the lower temperatures.

Plagge (1938) stated that the preservation of foods by freezing usually conserves vitamin C better than any other method. This vitamin is rapidly lost, however, during defrosting.

Enzymes play an important part in the storage of frozen foods. Joslyn and Marsh (1933) found that blanching before freezing prevented discoloration and development of off-flavors during storage. Kertesz, Dearborn and Mack (1936) also found that blanching prevented the loss of vitamin C by inactivating the ascorbic acid enzymes. Joslyn (1930) stated that the oxidase system in fruits is not inactivated even at 0°F. and because of the formation of ice crystals, the cell constituents of frozen foods are intimately mixed, thus facilitating spoilage.

According to Jenkins, Tressler and Fitzgerald (1938) the vitamin C of frozen blanched peas is retained completely at 30°F. for at least ten hours but 81 percent is lost when stored seven weeks at 19°F. Frozen peas showed no loss of ascorbic acid when thawed at room temperature. Fenton and Tressler (1938) confirmed these results, finding no loss of vitamin C in frozen peas thawed for 16 hours at 40°F. On the other hand, Fellers and Stepat (1935) reported losses up to 70 percent of the vitamin C content of frozen peas in thawing for two to six hours at room temperatures.

Frozen sweet corn was reported as losing five percent of its vitamin C when stored one day at room temperature by Dunker, Fellers and Fitzgerald (1937) while frozen spinach lost 47 percent at room temperature in three days. (U. S. Dept. Agric., 1939).

Jenkins, Tressler and Fitzgerald (1938) found that while storage of frozen snap beans, peas, broccoli, spinach and sweet corn for two weeks at 16°F. resulted in losses of vitamin C up to 13 percent, only fractional losses resulted when the temperature was lowered five degrees. Diehl and Berry (1933) reported that a temperature of -5°F. was necessary to retain the green color of frozen peas. At higher storage temperatures such as 15° to 25°F. the peas turned yellow.

The loss of vitamin A in quick frozen foods is reported to be negligible by Fellers (1940). Other food constituents such as carbohydrates, proteins, fats or minerals are also retained during both storage and thawing according to Tressler and Evers (1936).

Tressler (1938) stated that properly prepared frozen vegetables should contain less than 100,000 bacteria per gram. Fluctuating temperatures were found to cause an excessive desiccation or freezer burn. At 15°F. most frozen vegetables were found to lose color, flavor, aroma and vitamin C and slight amounts of vitamin A when stored longer than two months.

Food Spoilage

The prevention of spoilage is the primary purpose of refrigeration and naturally there has been a large amount of work carried on in this field.

The importance of refrigeration was pointed out by an anonymous investigator (1931-A) who stated that 99 percent of the cases of food intoxication encountered had their origin in the decomposition of foods because of improper refrigeration. Bacteria and yeasts are very active at temperatures between 70° and 80°F. according to Tressler and Evers (1936). This activity is retarded by lower temperatures until at 15°F. for fruits and 10°F. for vegetables, growth is practically negligible.

Boyer and Fittz (1932) reported that between 50° and 60°F. bacteria multiply 400 times as fast as between 40° and 50°F., and therefore refrigeration temperatures should be less than 50°F. Maintenance of this temperature is difficult in an ice refrigerator. Tanner and Oglesby (1936) also found foods would keep a long time at 50°F. or less while no bacterial growth occurred at 41°F.

Beckwith (1936) studied the conditions of temperature, moisture content, acidity and oxygen supply under which mold growth is retarded. Moulton (1929) reported that the growth of Clostridium sporogenes was retarded or stopped at 38°F. while mold growth was retarded but not stopped at this temperature. According to Tressler and DuBois (1940) most bacteria and yeasts are inactivated just below 32°F. but molds grow slowly even at lower temperatures.

Prescott (1932) found temperatures of 45°F. or less necessary for the storage of meat in the home for a period of four days. The rate of multiplication of the various types of organisms usually found in food was investigated at different temperatures. Some of the organisms were found to be cold-loving and grew well at 45-50°F. while others did not multiply even at 60°F.

Stanley (1930) noted that growth of bacteria on beef was checked at temperatures of 40°F. and lower. A moderate increase in growth occurred at 45°F. and a decided increase at higher temperatures. Greater growth was found to occur on meats in covered dishes, due to the high humidity. Uncovered dishes caused the surface layers of the meat to become dehydrated and form a hard skin; therefore, there was less penetration of bacteria and less growth due to the unfavorable conditions.

Fresh beef spoiled only when stored for 30 days or more at 35-39°F. according to Richardson and Scherubel (1909) but was in very good condition when kept up to 14 days.

Berry (1941) in studying the bacterial content of strawberries found more organisms present at the end of six hours' storage at 90°F. than at the end of 24 hours at 70°F. or 42 hours at 40°F. Berry (1938) also found that the bacteria content of peas did not increase during storage for 24 hours at 30°F. but showed a count of from one to eight million per gram when kept at 70°F.

Diehl, Campbell and Berry (1936) observed that raw scalded peas did not increase their bacterial content when stored at 32°F. for 48 hours but at 70°F. there was a significant increase, their green color was lost and a sour odor developed. Berry (1937) found that during thawing frozen peas reached a room temperature of 65°F. in 13 hours and were spoiled in 24 hours, the bacteria increasing from 30 million to 600 million. Frozen peas stored at

40°F. in a refrigerator did not give visual evidence of bacterial growth until the third day, while they kept for over four days on some occasions.

Frozen spinach, peas and lima beans when defrosted at 71°F. spoiled in 12 hours but did not spoil until the end of 36 to 48 hours at 43°F., according to Brown (1933). Tanner, Beamer and Rickher (1940) investigated the development of Clostridium botulinum in frozen foods and reported no toxic substances formed at 41°F. for storage periods up to 14 days. At higher temperatures the formation of toxin was dependent on the acidity of the media.

Luxwolda (1912) noted that at temperatures between 37-41°F. all milk bacteria ceased growth with the exception of Pseudomonas fluorescens. The importance of refrigeration in the preservation of milk was demonstrated by Bowen (1932). It was shown that a reduction in the storage temperature of from 68° to 50°F. decreased the number of bacteria present in milk after 24 hours 1,500 times and resulted in a 60,000 fold reduction after 48 hours' storage. The bacterial count of milk stored at 70°F. was 150 times that when it was stored at 50°F., according to Parfitt (1925). Acidophilus milk of good quality could be stored at 41°F. for from two to seven days if the acidity was not greater than 0.65 percent at the start, according to Kulp (1931).

As far as the pathogenic organisms in foods are concerned, Ruzicka (1921) stated that low temperatures and high acidity prevented the growth of typhoid, paratyphoid, dysentery and cholera organisms on foods. Prescott and Tanner (1938) found that food poisoning organisms of the Salmonella group would not grow at 41°F. or less. Prescott and Greer (1936), however, reported temperatures not greater than 39°F. as necessary for the prevention of spoilage due to the Salmonella group. Clostridium botulinum was prevented from forning toxins for extended periods at any temperature below 50°F. Staphylococcus food poisoning organisms on the other hand were found to grow under refrigeration, after a lag of a day, although not as rapidly as at room temperature.

Segalove and Dack (1941) reported the production of enterotoxin by Staphylococci in three days at 65°F. and after seven days at 48°F. At temperatures between 39° and 44°F., however, none was found even at the end of four weeks.

Schmid (1931) showed that the growth of bacteria is dependent on the temperature and humidity as well as on the time. At 32°F. meat could be kept ten days at 95 percent relative humidity but at 39°F. the humidity had to be lowered to 75 percent in order to prevent spoilage in this same period. At 85 percent relative humidity, meat kept only six days at 39°F. and at 100 percent only five days. It was further reported that in order to keep the bacterial count low in meat, the relative humidity at

38°F. must be less than 70 percent. The bacterial growth is an exponential function of the relative humidity, other conditions being constant.

Piqué (1938) found in studying the effect of humidity on the growth of organisms on bacon fat at 59°F. that at relative humidities of 60 percent, no visable growth occurred in two weeks, but at 90 percent humidity mold growth was found and at 100 percent yeasts covered the surfaces.

Bates and Highlands (1934) studied the rate of air movement as well as the relative humidity and found that at high humidities, relatively high air velocities can be maintained without undue dehydration. At lower humidities, for instance 88 percent, the rate of increase in bacteria was decreased slightly by increasing the air velocity. At 77 percent relative humidity the multiplication of bacteria showed a sharp decrease at the higher air velocities due to dehydration.

In investigating the growth of bacteria in frozen foods Haines (1937) noted that most bacteria ceased growth at 26°F. and most of the mold fungi at about 19°F. He concluded that in storage at 14°F. there is no microbial growth. The only changes at this temperature are slow chemical and enzymatic changes due to the enzymes in the food itself, or to those of bacteria, when they are present in large numbers. The primary bacterial infection of peas was not important if they were kept frozen until prepared for consumption.

Carleton (1941) reported that enzymes were only retarded by cold and were not destroyed, even at -400°F. Therefore, it would seem that there may be enzymatic changes occurring in frozen foods, however slow, at all storage temperatures used today, unless these enzymes have been inactivated by some means. The lower limit of microbial growth is now believed to be 15° to 20°F., approximately 90 percent of the bacteria being killed by the cold while the rest may live for years. In thawing frozen foods, the cell contents are liberated because of the destruction of the tissues during freezing and conditions are such that excessive bacterial growth is prone to take place.

Lochhead and Jones (1936) found that bacteria predominated in frozen vegetables, and yeasts and molds in frozen acid fruits. The development of microorganisms was appreciable at temperatures between 41° and 50°F. and enormous at room temperatures.

Prescott, Bates and Highlands (1933) found the number of organisms in a wide variety of frozen foods to be small and to decrease on long storage. They concluded that any physical or chemical changes occurring must be due to enzymes rather than the action of bacteria.

Summary

Domestic refrigeration is the most satisfactory means of preserving food for short periods. Refrigeration cannot improve an inferior food but it does retard spoilage, prevent changes in flavor and appearance, and preserve the nutritive value of good foods.

The electric refrigerator is superior to the ice box both economically and in efficiency of preservation.

Optimum Conditions of Refrigeration

The optimum conditions of home refrigerated storage appear to be a temperature of 40°F., restricted air movement, and high humidities, except in the case of meats. Meats should be wrapped rather than covered, and stored in the meat compartment provided in the modern refrigerators or directly under the drip pan in the older boxes.

To maintain these optimum conditions, left-over foods should be stored in covered dishes and fresh vegetables placed in hydrators. The covered dishes prevent transfer of flavor as well as dehydration and loss of vitamins. Frozen foods can be stored in the freezing compartment for short lengths of time.

Preservation of Nutritive Values of Foods

The destruction of vitamins A, B_1 and C is greatly reduced by proper refrigeration, while other nutritive values such as protein, minerals, carbohydrates and fats are unchanged by low temperatures.

Food Spoilage

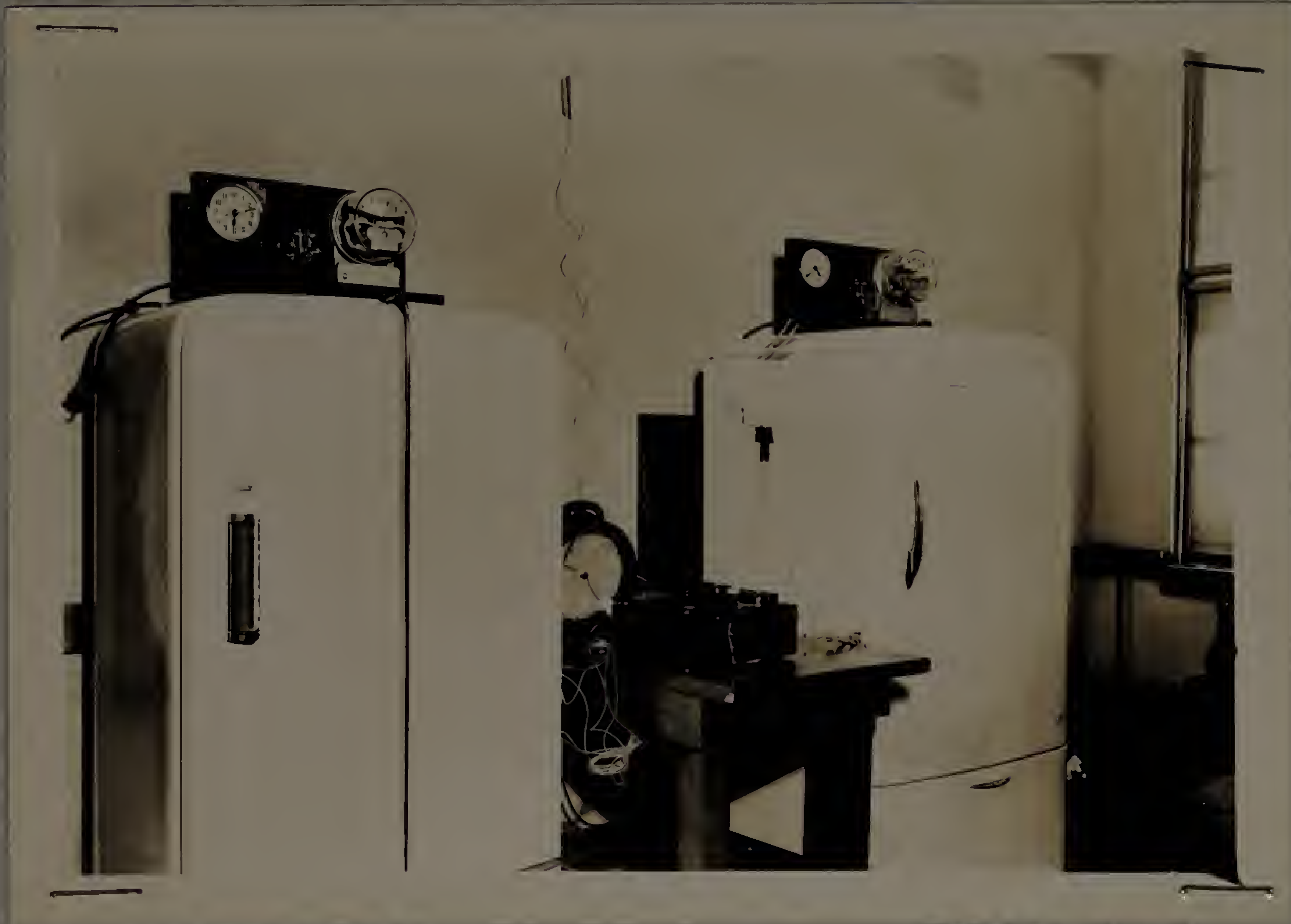
The multiplication of microorganisms is greatly retarded at temperatures between 40° and 50°F. Most ordinary pathogens are prevented from multiplying at 39°F., so that any food in good condition can be safely stored in a refrigerator for reasonable lengths of time.

GENERAL EXPERIMENTAL PROCEDURE

Two standard 1941 electric refrigerators were used in these tests. Plate I shows the two refrigerators, together with some of the equipment used to measure temperatures and power consumption.

Refrigerator G had an eight cubic foot capacity and was of conventional construction, that is, cooled by an exposed evaporator situated at the top of the storage chamber. The temperature differential between the cooling coils and the air in the cabinet of a refrigerator of this type is approximately 15°F. for normal running conditions; thus considerable air circulation is set up by the warm air rising to the top of the cabinet, being cooled, and sinking again. This large difference in temperature also results in a condensation of the moisture in the air on the coils as frost, so that a relatively low humidity is maintained in the box.

Refrigerator F was a six cubic foot model and of the newer high humidity type. The coils in this type of box have a much larger cooling surface, so that a temperature differential of only a few degrees has to be maintained. As they are imbedded in the walls of the box and not concentrated in one part of the cabinet, only a slight circulation of air occurs and no frost is formed, so that a high relative humidity is maintained. The humidity in



Refrigerator F Refrigerator G

Plate I. Storage Equipment

this box can be adjusted, to a certain extent, by opening or closing vents into the freezing compartment, which has cooling surfaces similar to those of the low humidity type of refrigerator.

All foods, except the eggs, which were obtained from the Poultry Department, were purchased locally in the open market and prepared as they would be in the home.

Physical Determinations

The two refrigerators were set up in a room in which the temperature was kept as near constant as possible, varying only by about 10°F. during any one day. The temperature usually ran between 70° and 80°F., reaching a maximum around 2:00 p.m. each day.

Power Consumption

A watt hour meter and an electric time clock were connected in the circuit of each box so that the running time and watt hours consumed could be read. Thus the per-cent running time and watts could be calculated for each refrigerator to keep a check on their proper functioning.

Temperature

A standard practice of using the Fahrenheit scale for all temperature measurements was followed throughout this work.

Recording thermometers were used to record the changes in temperature both in the room and in the refrigerator cabinets, while thermocouples were used for the accurate measurement of the temperatures. The potentiometer was checked against a mercury thermometer before taking the readings.

Thermocouples were set eight feet, four feet, and ten inches above the floor between the two boxes to determine the room temperature. A thermocouple was placed in the centre and about two inches above each refrigerator shelf for the box temperatures. Two other thermocouples were placed in the lower chamber of the freezing compartments for the temperature of the air. One was centered on the back wall while the other was suspended one inch from the roof directly in the centre of the chamber. Two more thermocouples were placed in the freezing compartment to be inserted in the frozen food cartons placed therein.

The evaporator temperatures were measured by means of special thermocouples, the junctures of which were soldered to small flat copper plates. Thus the thermocouple could be placed directly in contact with the surface of the coils. These were placed on the top and bottom coils of the freezing compartment.

All thermocouples were connected to a selector switch which in turn was connected to a potentiometer with a scale calibrated in Centigrade units. The temperature readings in degrees Centigrade were converted to degrees Fahrenheit.

Humidity

Different humidities were obtained by the use of closed containers and by varying the refrigerator loads and door openings. The humidity of the cabinet was measured by means of wet bulbs made up of thermocouples wound with a wick of unbleached linen and mounted, together with a well, on small stands. The wet bulbs were standardized by means of a sling psychrometer at room temperature to within 1°F. and the correction taken. At least three wet bulbs were used in each box and the lowest readings were used. When a wet bulb appeared to be off it was removed from the cabinet, checked with a sling psychrometer and re-wound, if necessary. Readings were made at the beginning and end of at least two consecutive periods when the motor was in operation and the mean temperature and humidity calculated. The readings were made after the boxes had been at rest at least six hours so that the box had had time to reach a constant temperature.

Dehydration

Loss of moisture was determined by direct weighing of the samples while in their containers, to the nearest tenth of a gram. The amount of dehydration of the foods themselves, in the tests on left-overs, was found by moisture determinations. The Bidwell-Stirling method, according to A.O.A.C. (1940) was used first, but due to the number of samples it was found more expedient to dry the samples at 135°C. in an electric air oven, according to the method given in the A.O.A.C. (1940).

pH Determination

The pH measurements were made by means of a Beckman pH meter, using glass and calomel electrodes.

Measurement of Flavor Transfer

Besides organoleptic tests the rate of flavor transfer was measured by titrating with one normal sodium hydroxide the amount of acetic acid absorbed by dishes of water from the atmosphere in the refrigerator. Uncovered dishes containing five percent acetic acid were used as emitters.

Determination of Relative Quality

The grade of the eggs was determined by candling and their relative quality measured by comparing the odor, loss in weight, increase in air cell size and by an examination of the egg albumin for appearance and texture.

Organoleptic, vitamin C tests and bacterial counts were made to evaluate the relative quality of the samples of vegetables and fruits under the different storage conditions. The organoleptic tests included a comparison of odor, taste, texture, surface discoloration and drying, and general appearance.

The bacterial counts were made by plate counts using the method developed by Geer, Murray and Smith (1933) for the bacteriological examination of meat.

The ascorbic acid content of the foods was determined whenever possible, because, according to Fitzgerald (1938), vitamin C is the best index of quality of fruits and vegetables, practically parallelling variety, overmaturity, storage time and overcooking. This is substantiated by Henderson, Foord and Roodhouse (1940) who found a close relationship between the destruction of ascorbic acid and the deterioration in flavor of milk.

Mack, Tapley and King (1939) and Shrader (1940) also found that the retention of vitamin C parallels the factors which determine the quality of snap beans and lima beans respectively, while Bukin and Stupak (1937) found that the varieties of cabbage which did not keep well lost more vitamin C and at a faster rate than those which had good keeping qualities.

Tressler, Mack, Jenkins and King (1937) stated that every factor which detracts from quality also causes a loss of vitamin C in lima beans. Tressler (1938), also, found vitamin C to be an excellent index of the quality of frozen vegetables.

Because of its wide use and accuracy, the ascorbic acid content was determined by the visual titration method, using the dye 2,6-dichlorophenolindophenol as suggested by

Tillmans, Hirsch and Hirsch (1932) and described by Maclinn and Fellers (1938).

As we were more interested in the changes occurring in the foods during storage, rather than their total antiscorbutic value, the reversibly oxidized ascorbic acid, dehydroascorbic, which might have been present naturally in some of the foods, was not determined.

Extractions and dilutions were made with an acid mixture consisting of two percent metophosphoric and five percent sulphuric acids. As Mack and Tressler (1937) found, this mixture with its low pH of about 0.8 prevented the oxidation of l-ascorbic acid to dehydroascorbic acid during the extraction and titration.

A 0.05 percent dye solution was used and was standardized each day by titrating the iodine liberated by the dye from a potassium iodide solution with 0.01 normal sodium thiosulphate which in turn had been standardized in the usual manner by means of a standard potassium iodate solution, a method worked out by Buck and Ritchie (1938) and Menaker and Guerrant (1938).

At first 25 gram representative samples were selected for the ascorbic acid determination. However, due to the variation in results it was later found preferable to grind the whole storage sample and then sample this mass.

The ascorbic acid was extracted from the 25 gram samples by grinding in a mortar with the acid solution and acid washed sand, and then centrifuging to separate the pulp and serum. As recommended by Maclinn and Fellers (1938) two extractions were made in order to get a more quantitative yield. This procedure extracts all but about 1.5 percent of the ascorbic acid, in tomatoes, according to these authors. The serum was then made up to 200 milliliters and 25 milliliter aliquots titrated with the dye in triplicate.

The titration was carried out as quickly as possible. A faint pink colored extract lasting for 30-40 seconds was taken as the end point. Any subsequent reduction of the dye was disregarded, as according to Evelyn, Malloy and Rosen (1938) the reaction between ascorbic acid and the indolphenol dye is almost instantaneous, while all other interfering substances which may be present react at a much slower rate at the low pH of the mixture.

The vitamin C content was calculated as milligrams per 100 grams of vegetable or fruit or in the cases where dehydration occurred, it was calculated as milligrams per gram of dry matter.

PART A - OPERATING CONDITIONS

Experimental Procedure

The refrigerators were adjusted so that they maintained a cabinet temperature within 1°F. of one another. Different conditions with regard to door openings and food load were set up to determine their effects on the operation of the refrigerators.

The temperature and relative humidity of the refrigerators were determined when the boxes were empty and again when a normal size load was present. The loads consisted of representative foods and jars of water. A tray of ice cubes was frozen each day and articles replaced by ones at room temperature in order to simulate home conditions. An average of 25 door openings per day were made in both these tests.

The change in the humidity caused by opening the doors of the unloaded boxes was also determined.

The daily power consumption was calculated from the kilowatt hour and running time readings for each of the above conditions.

Presentation of Results

Effect of Load on Temperature and Humidity

There was no noticeable effect on the average running temperature of the boxes caused by the loads. Large quantities of hot materials did cause a temporary rise in temperature, of course.

From Table 3 it may be seen that refrigerator F always maintained a 15-20 percent higher relative humidity than refrigerator G. The presence of a medium size load caused an increase of 10-15 percent in the humidity of both refrigerators.

Effect of Door Openings on Temperature and Relative Humidity

Table 3 shows that door openings caused a 10 percent increase in the humidity of each refrigerator.

Both boxes kept a fairly constant temperature (within 1°F.) when left at rest. However, the door openings had a marked effect on the temperature of the cabinets, due to the denser cold air literally falling out and being replaced by warmer air from the surroundings. The rise in temperature was, of course, governed by the number of openings made, their duration and frequency.

Figures 1 and 2 were taken from typical temperature charts and illustrate the effects of door openings on the box temperature. Both types of boxes acted similarly.

The normal running temperature of a domestic refrigerator is 40°F. From Figures 1 and 2 it may be seen that a single door opening for 30 seconds caused a rise in temperature of five degrees while a six degree rise was caused when the time was doubled. When two door openings were made within five minutes of one another, the tempera-

Figure 1. Effect of Door Openings on Refrigerator Temperature

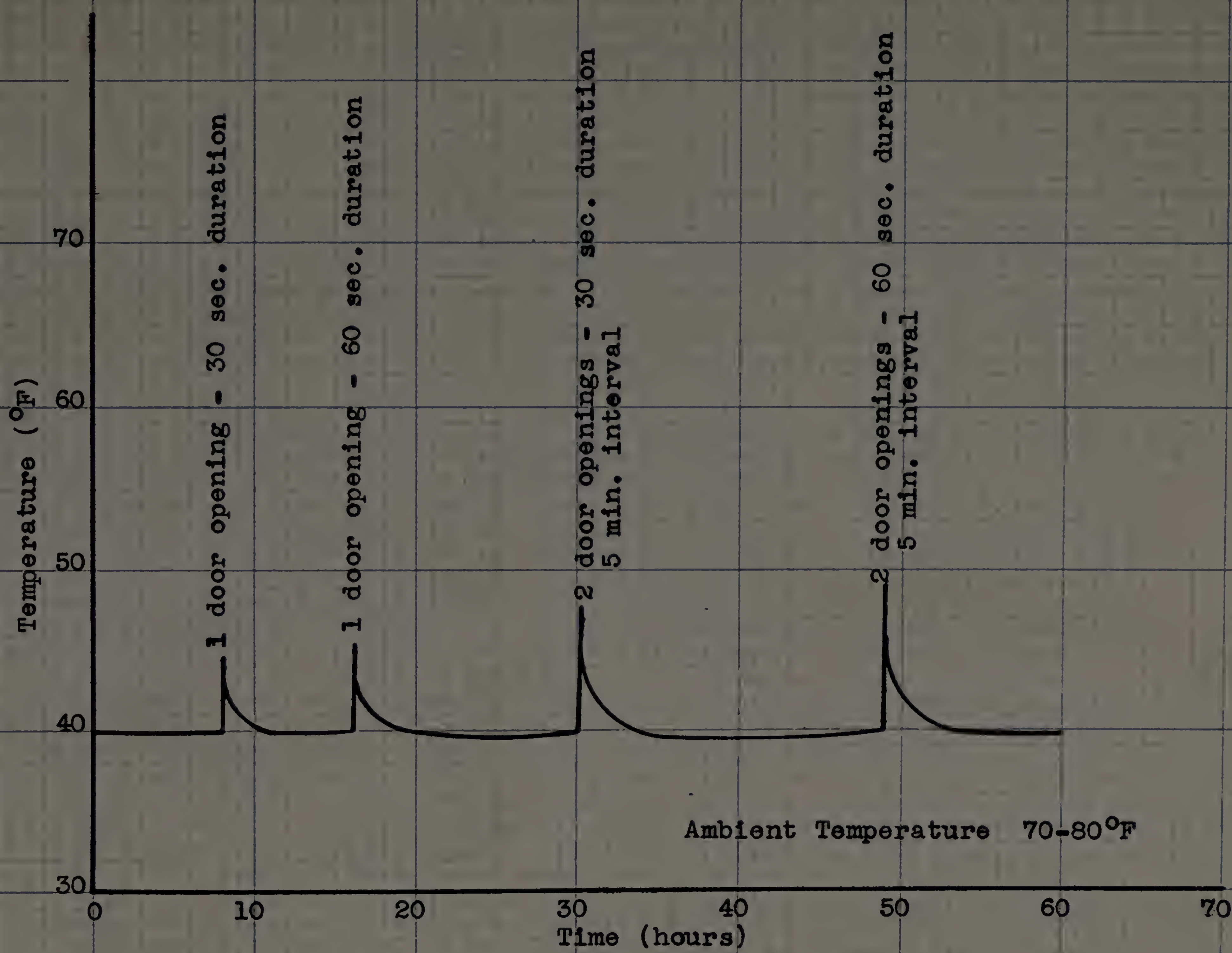


Figure 2. Effect of Door Openings on Refrigerator Temperature

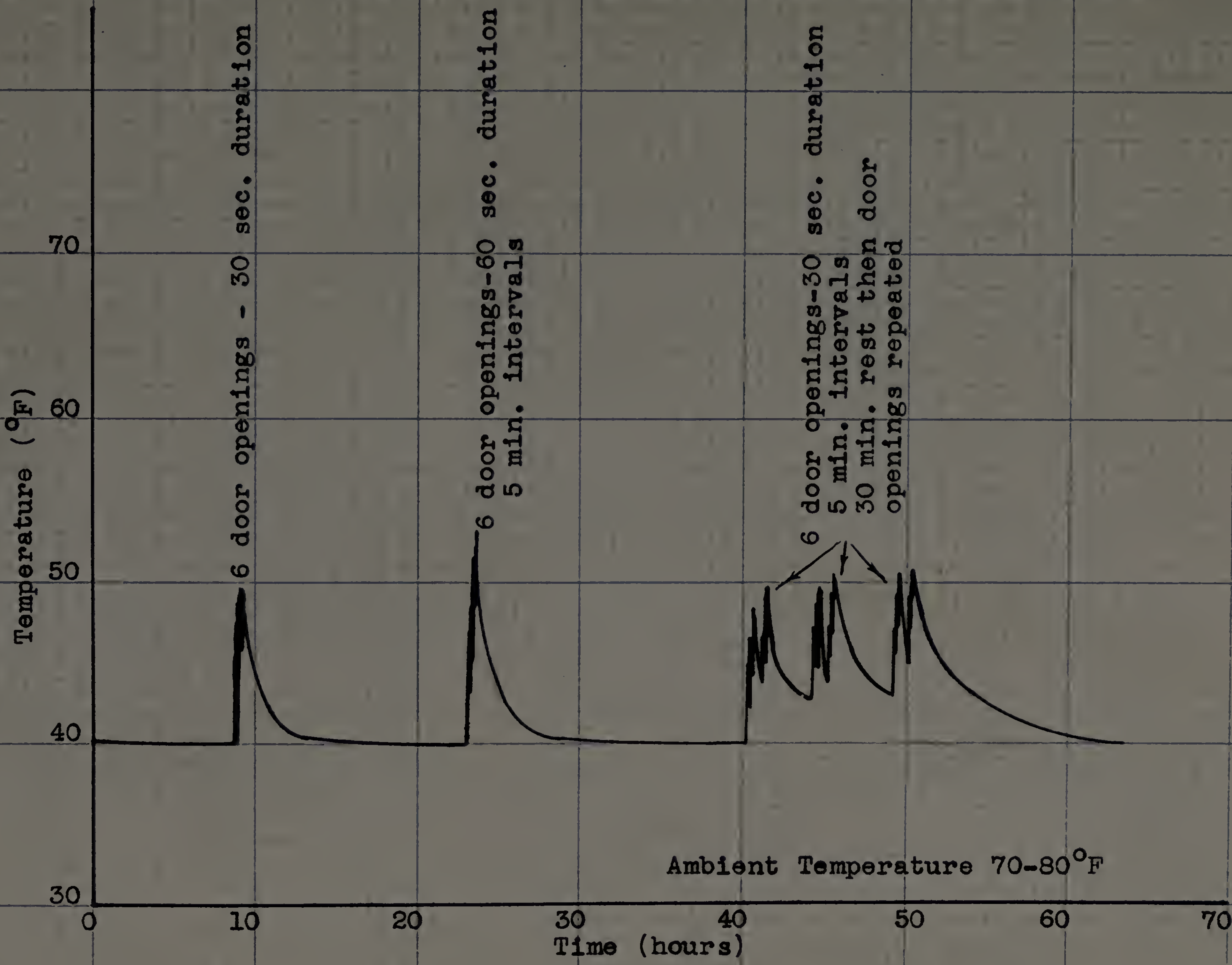


Table 3. Effects of load and door openings on refrigerator humidities at 41°F.

Cabinet	Relative humidity Unloaded	Unloaded	Loaded
Doors	Closed	Opened*	Opened*
	percent	percent	percent
Refrigerator G	41	51	61
Refrigerator F	55	65	80

* Opened 25 times per day.

ture rose about eight and nine degrees when the doors were kept open 30 and 60 seconds, respectively.

Six door openings occurring within five minutes of one another and for 30 and 60 seconds duration gave rises in temperature of nine and thirteen degrees, respectively.

When six door openings were made within five minutes of one another and for 30 seconds duration each, the box left at rest for one-half hour and then six similar door openings made, the maximum rise in temperature was 11 degrees. This may be considered to approximate conditions during a meal hour.

The recovery of the refrigerators to normal temperature was quite rapid. Taking the time to recover to within two degrees of normal, it may be seen that for one or two door openings, this temperature is reached in from one-half to one hour.

After a series of door openings the recovery time was longer, being one and one-half hours to reach 42°F., for a series of six door openings, while for 12 openings within an hour and a half, the time required was three and one-half hours. It should be noted that when these openings were made during the three meal hours of a day, the mean temperature was approximately five degrees higher than the theoretical setting for about 12 hours, or 50 percent of the time.

The rise in temperature seemed to be influenced by the length of time the doors were left open and also by the number of openings, the latter having the greatest effect. For example, two openings for 30 seconds each caused a greater increase in temperature than one opening for one minute's duration.

Although the door openings did cause these fluctuations in the refrigerator temperatures, the increases in temperature did not noticeably affect the keeping qualities of the foods.

Effect of Load, Door Openings and Operating Temperatures on Power Consumption

No great difference was noted in the power consumption of the refrigerators when different size loads were present.

Table 4 shows the effect of door openings and operating temperature on the power consumption. The door openings caused an increase in power consumption of from nine to eleven percent.

A decrease in the operating temperature of only six degrees, to 35°F., required 80 percent more energy than that required at 41°F.

Discussion

The home refrigerator should be operated at the temperature recommended by the manufacturer, which is usually 40°F. Operation at lower temperatures increases the power consumption tremendously while higher temperatures are not as efficient for the storage of food.

Table 4. Effect of door openings and operating temperatures on the power consumption of loaded domestic boxes

Refrigerator	Temperature	Door openings per day	Kilowatt hours consumed per day
	Fah.		
F	41°	none	0.606
F	41°	25	0.675
G	41°	none	0.550
G	41°	25	0.600
G	35°	25	1.082

The humidity of the boxes was increased by door openings, due to the entrance of air from the room which, being at a much higher temperature, contained relatively large quantities of moisture.

Refrigerator door openings seemed to remove a part of the cooled air from the box so that two door openings caused a higher temperature rise than one, although the total time the door remained open was the same in both cases.

In order to keep the fluctuations in refrigerators, caused by door openings, at a minimum, it might be recommended that during preparation of meals the housewife remove as many articles as possible at one time rather than make several individual trips to the refrigerator and at the same time keep the door open for as short a time as possible.

PART B - EGG STORAGE

Experimental Procedure

Strictly fresh eggs* were selected for uniform shape and size and stored in one dozen lots in various types of containers and at different humidities at approximately 41°F. The purpose of this study was to determine how long eggs may be safely stored and the optimum storage conditions.

To determine the amount of deterioration, samples were candled each week and the loss of weight determined by direct weighing. The air cell was outlined in pencil and the relative increase determined by measuring the increase in size of the periphery. Samples were also broken and examined for changes in the albumin.

Presentation of Results

Deterioration in Quality

At 41°F. and at humidities of 40-100 percent, no evidence of mold growth was found in the eggs and all samples still candled to Grade A specifications, even at the end of four weeks' storage.

No changes in the appearance of the albumin could be attributed to the various methods of storage.

Loss of weight and the increase in the size of the air cell was not excessive under any of the conditions.

* Acknowledgment - The eggs were supplied, selected and graded through the courtesy of Mr. John H. Vondell, Poultry Department, Massachusetts State College.

Effect of Humidity on the Quality of Eggs

The average loss of weight of the various samples is given in Table 5 and plotted in Figure 3. It may be seen that the eggs in covered dishes (100 percent relative humidity) actually showed a gain in weight, amounting to almost 0.5 percent in four weeks.

There was a gradual loss of weight of the eggs stored loosely in wire baskets which was inversely proportional to the humidity; the eggs stored at 40 percent relative humidity lost 2.0 percent of their weight in a month while those stored at 58 percent humidity lost only about one percent.

Table 6 and Figure 4 show that storage in 100 percent relative humidity causes a relatively small increase in the size of the air cell. The rate of increase in air cell size of the wire basket samples was approximately the same in every case for three weeks but at the end of four weeks the samples stored at 40 percent humidity had a 20 percent larger air cell than the eggs stored at 58 percent relative humidity.

The air cells of the covered samples increased as rapidly as the others during the first week and then became fairly constant.

The loss of weight and increase in size of the air cell were therefore proportional to the length of storage and the aridity.

Table 5. Loss of weight of eggs during storage at 41°F.

	Relative humidity	Weeks stored 1	2	3	4
		Average loss of weight			
	percent	percent	percent	percent	percent
Wire baskets	40	0.3	0.6	1.1	2.0
Wire baskets	58	0.0	0.2	0.2	0.9
Cartons (refrigerator G)	40	0.6	0.9	1.9	1.9
Cartons (refrigerator F)	58	0.5	0.6	1.0	1.3
Covered dishes	100	0.0	+0.2	+0.4	+0.4

Table 6. Relative increase in size of air cell of eggs during storage at 41°F.

	Relative humidity	Weeks stored 1	2	3	4
		Increase in periphery of air cell			
	percent	mm	mm	mm	mm
Wire baskets	40	4.5	6.2	7.8	11.2
Wire baskets	58	3.7	5.9	7.5	8.4
Cartons (refrigerator G)	40	2.5	3.0	6.6	7.8
Cartons (refrigerator F)	58	2.7	5.3	7.1	7.8
Covered dishes	100	2.5	3.6	2.8	3.1

Figure 3. Loss of Weight of Eggs Stored at 41°F

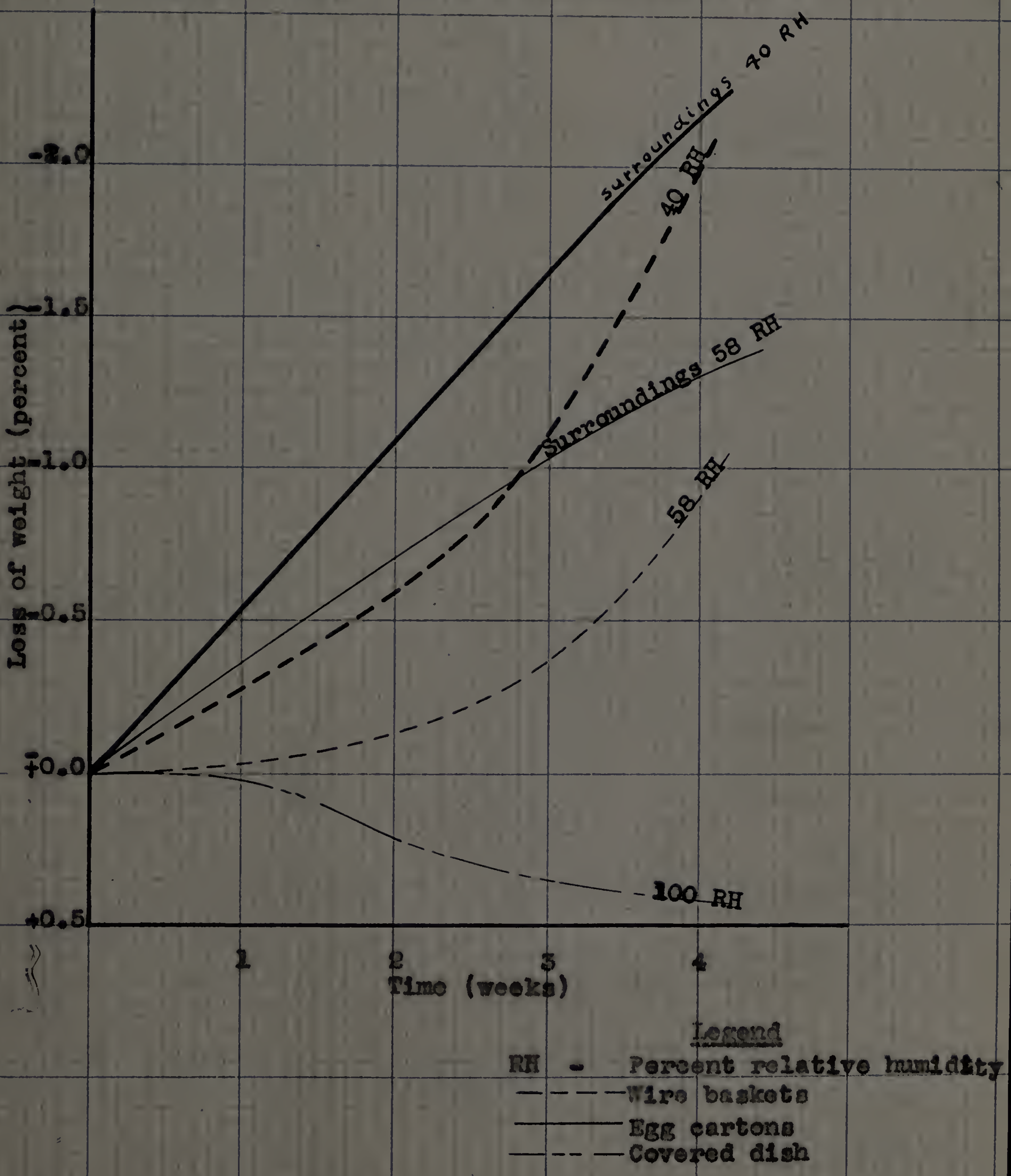
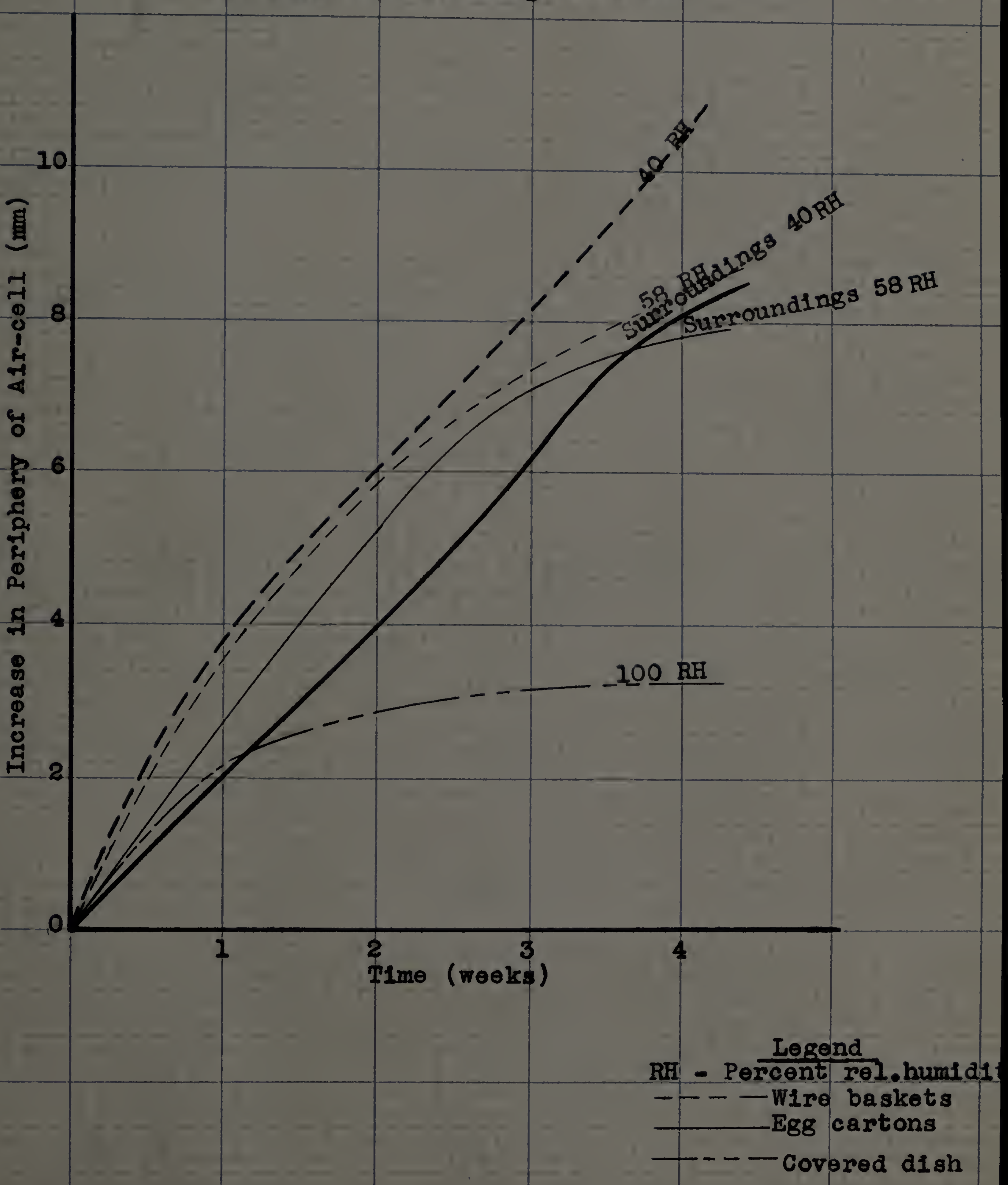


Figure 4. Relative Increase in Air-cell Size of Eggs during Storage at 41°F



<u>Effect of Containers on the Quality of Eggs</u>

Three methods of storage were used in these tests: (1) the eggs were stored loosely in wire baskets placed in the refrigerator; (2) they were stored in glass covered dishes and (3) in conventional cardboard egg boxes.

Any changes in the eggs in (1) or (2) would be due to the effect of humidity and is discussed above. Owing to evaporation from the eggs the humidity inside the egg cartons must have been higher than that of their surroundings. However, as can be seen from Figure 3 there was a much greater loss of weight in the case of the eggs in the cartons than in those stored loosely in the same refrigerator.

The increase in air cell size of the eggs in the cartons was less than that of those stored loosely in the refrigerators.

Discussion

If fresh eggs can be purchased more economically in quantity it is evident that they may be safely stored in the ordinary domestic refrigerator in any ordinary manner for at least a month without serious deterioration and used as needed.

The absence of mold growth in the eggs stored at 100 percent relative humidity and 41°F. is contradictory to the findings of Smith (1930) who encountered slight evidence of mold in nine days under these conditions and severe growth in 18 days. The shells of the eggs stored in the covered dishes were observed to be damp and it is assumed the increase in weight was due to absorption of moisture by the egg or possibly condensation on its surface.

The greater loss of weight of the eggs stored in the cardboard cartons is contrary to the finding that the loss of weight was proportional to the humidity. It was noticed, however, that all the cartons were quite damp and it is possible that the cardboard by absorbing moisture from the humid atmosphere immediately surrounding the eggs, actually accelerates the rate of evaporation.

It is evident that the increase in the size of the air cell is not caused entirely by the loss of moisture from the eggs.

Although none of the methods of storage resulted in a deterioration in grade, the optimum condition for the storage of eggs in ordinary domestic refrigerators for periods up to a month is in covered, non-porous containers, that is, 100 percent relative humidity and no air movement. This method of storage will obviously diminish the danger of absorption of flavors as well as prevent the loss of moisture.

PART C - STORAGE OF LEFT-OVER FOODS

Experimental Procedure

Various vegetables such as creamed mashed potatoes, frozen peas, frozen broccoli and canned snap beans were prepared for serving in the same manner as is used in the home. Samples were stored with portions of the cooking juices, if any, in corresponding positions in refrigerators F and G. Fresh tomatoes and radishes were sliced as for use in a salad and also stored as left-overs.

The refrigerators were set at their normal operating positions and their mean temperatures varied between 39° and 42°F. throughout the tests. The temperatures of the refrigerators themselves varied one from the other by only about 1°F.

Ordinary refrigerator dishes with loose fitting glass covers and small custard dishes which were provided with oiled silk covers were used as containers. The humidity in both types of covered dishes was 100 percent. The dishes were used both covered and uncovered so that a wide range of storage humidities (from 42 to 100 percent) was obtained. Thus it was possible to determine the effect of humidity on the keeping quality of the foods.

Ordinary household conditions of load and door openings were approximated in most cases but these conditions were varied in order to obtain different relative humidities in the boxes.

Several samples were prepared for each condition so that a complete sample was available each day for testing purposes.

The tests were run for at least four days and samples removed periodically to determine the loss in quality. The tests for quality consisted of determinations of the loss in weight, vitamin C content, moisture content, change in pH value and organoleptic tests. Bacterial counts were also run in some cases.

Approximately 25 gram samples were used for the ascorbic acid determinations. At first representative samples were taken directly from the stored foods but later it was found advisable to grind the whole storage sample and then sample the ground-up material for the ascorbic acid determination.

Due to the possibility of dehydration during storage especially at the lower humidities, the ascorbic acid content is reported on a dry weight basis.

Presentation of Results

Change in pH During Storage

In no instance did the pH value of any of the foods show a significant change. The maximum change in four days storage was only 0.4 pH units. No variation in pH value could be attributed to the differences in humidity, and the only governing conditions were found to be the length of storage.

From these results it was evident that the pH value was of no value as an indication of spoilage or autolytic changes in foods stored in a refrigerator.

Loss of Weight During Storage

Effect of Humidity on Loss of Weight - The percentage loss of weight of the various foods at the different storage humidities is presented in Table 7. For any one vegetable the same size sample was used and stored in similar containers. As the humidity was reduced from 100 percent there was a rapid loss of weight, due to the evaporation of water. This loss amounted to as much as 15 to 28 percent in four days at the lower humidities, even in the case of fresh vegetables stored without juice such as radishes, sliced tomatoes and mashed potatoes.

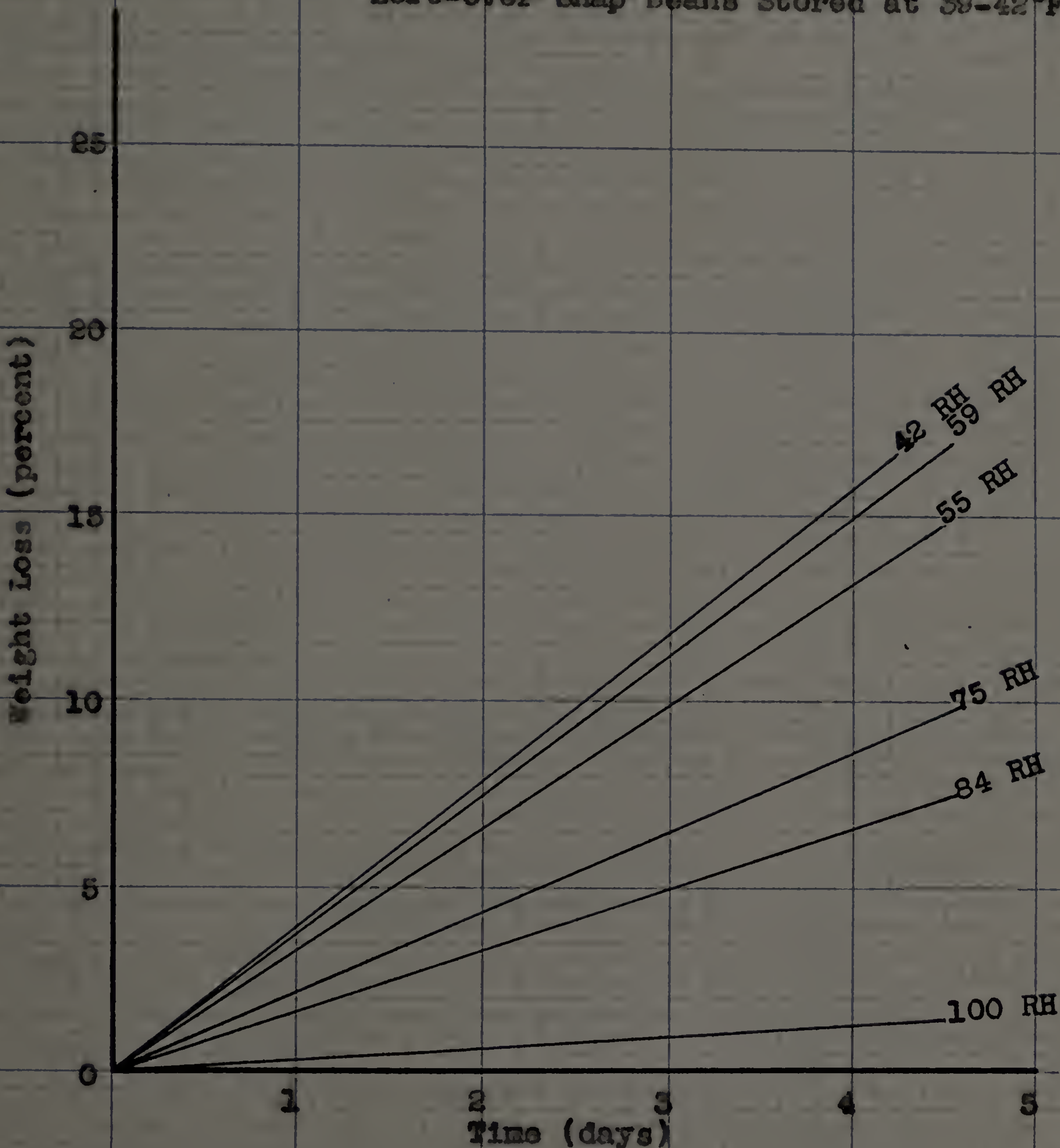
Humidities above 75 percent reduced the loss of weight to ten percent or less. At 100 percent humidity the loss in weight was only about one percent.

At 84 percent, the highest humidity obtained in the high humidity type of refrigerator, sliced tomatoes lost 13 percent of their weight in four days while snap beans lost only five percent. The loss of weight in left-over snap beans is plotted in Figure 5 to show the typical curves obtained. It should be noted that the loss of moisture appears to be a direct linear function of the time and depends on the relative humidity.

Table 7. Loss of weight in left-over vegetables during storage at 39°-42°F.

Days	Percent relative humidity 100	84	80	75	65	62	59	55	51	42
	Weight loss (percent)									
					Creamed mashed potatoes					
1	0.8	--	--	--	3.9	--	--	3.2	8.4	3.7
2	1.0	--	--	--	5.3	--	--	7.1	9.8	10.1
4	1.2	--	--	--	13.4	--	--	13.7	22.3	15.2
5	2.1	--	--	--	--	--	--	17.4	--	19.6
					Cooked frozen peas					
1	0.6	--	--	--	4.1	--	--	3.6	4.3	4.0
2	1.0	--	--	--	5.0	--	--	7.9	6.2	7.8
4	1.2	--	--	--	10.2	--	--	15.2	11.5	16.2
5	0.9	--	--	--	--	--	--	18.8	--	21.2
					Cooked frozen broccoli					
1	0.5	5.6	--	2.7	-	5.7	7.1	3.2	--	6.5
2	1.1	7.8	--	4.8	-	9.8	12.0	7.8	--	10.0
4	1.3	10.7	--	9.8	-	16.1	23.9	16.0	--	20.8
5	1.3	--	--	--	-	--	--	22.8	--	26.8
					Reheated canned snap beans					
1	0.5	2.0	--	2.8	-	--	4.2	4.3	--	3.5
2	0.7	3.9	--	4.5	-	--	9.0	6.0	--	8.0
4	1.0	5.1	--	7.6	-	--	11.6	11.8	--	15.6
5	1.5	--	--	--	-	--	--	14.4	--	20.5
					Sliced tomatoes					
1	0.1	2.2	2.8	--	5.5	6.6	--	3.4	--	5.4
2	0.1	5.0	4.8	--	9.6	10.8	--	9.2	--	6.7
4	0.6	13.1	8.9	--	18.6	14.6	--	17.1	--	17.4
					Scored radishes					
1	0.0	--	--	--	--	--	--	6.7	--	6.3
2	+0.3	--	--	--	--	--	--	7.6	--	14.8
4	+0.2	--	--	--	--	--	--	23.7	--	28.3

Figure 5. Effect of Humidity on Loss of Weight in Left-over Snap Beans Stored at 39-42°F



RH - Percent relative humidity

Figure 6. Effect of Humidity on Loss of Weight in Left-overs Stored Four Days at 39-42°F

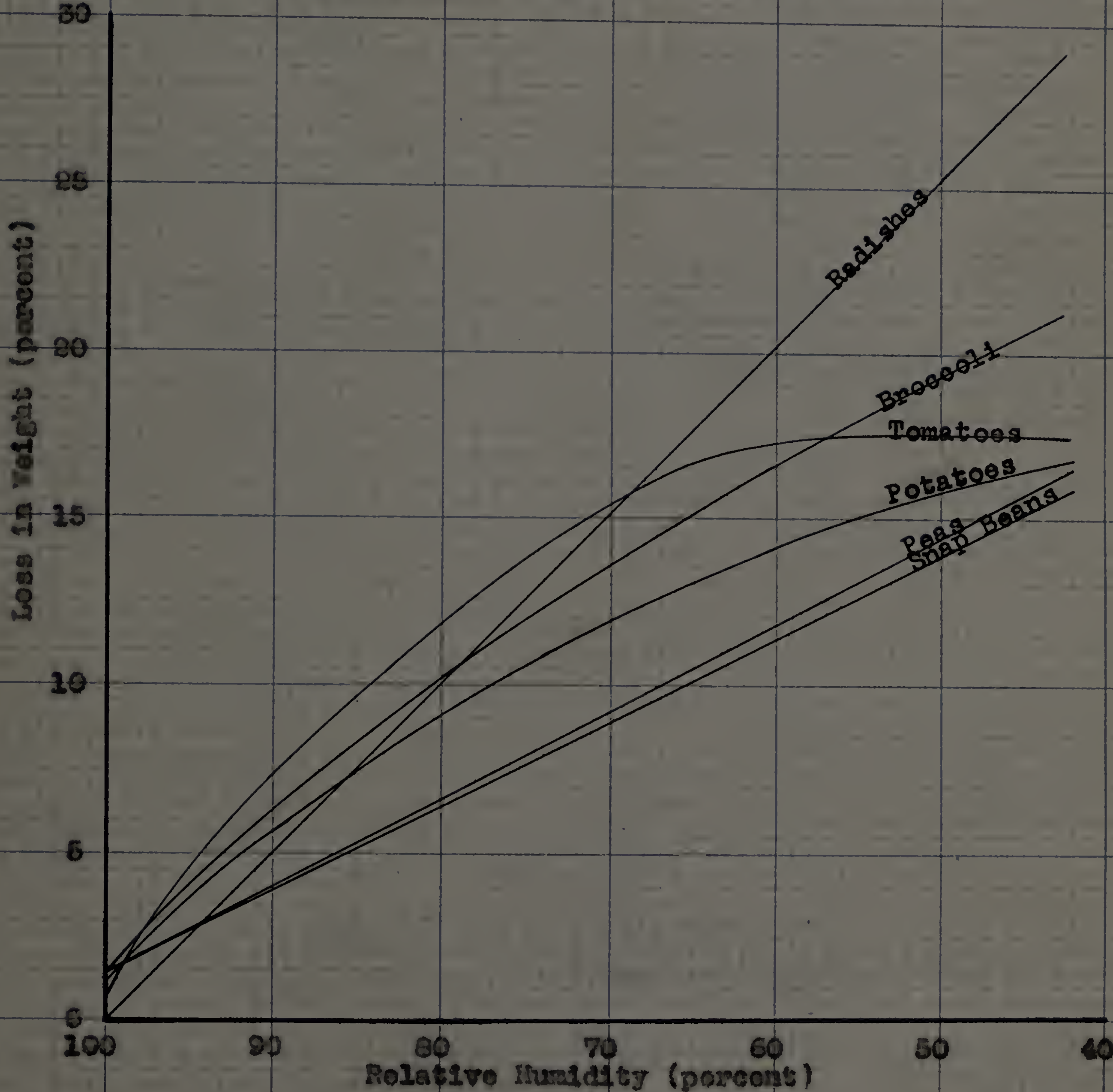
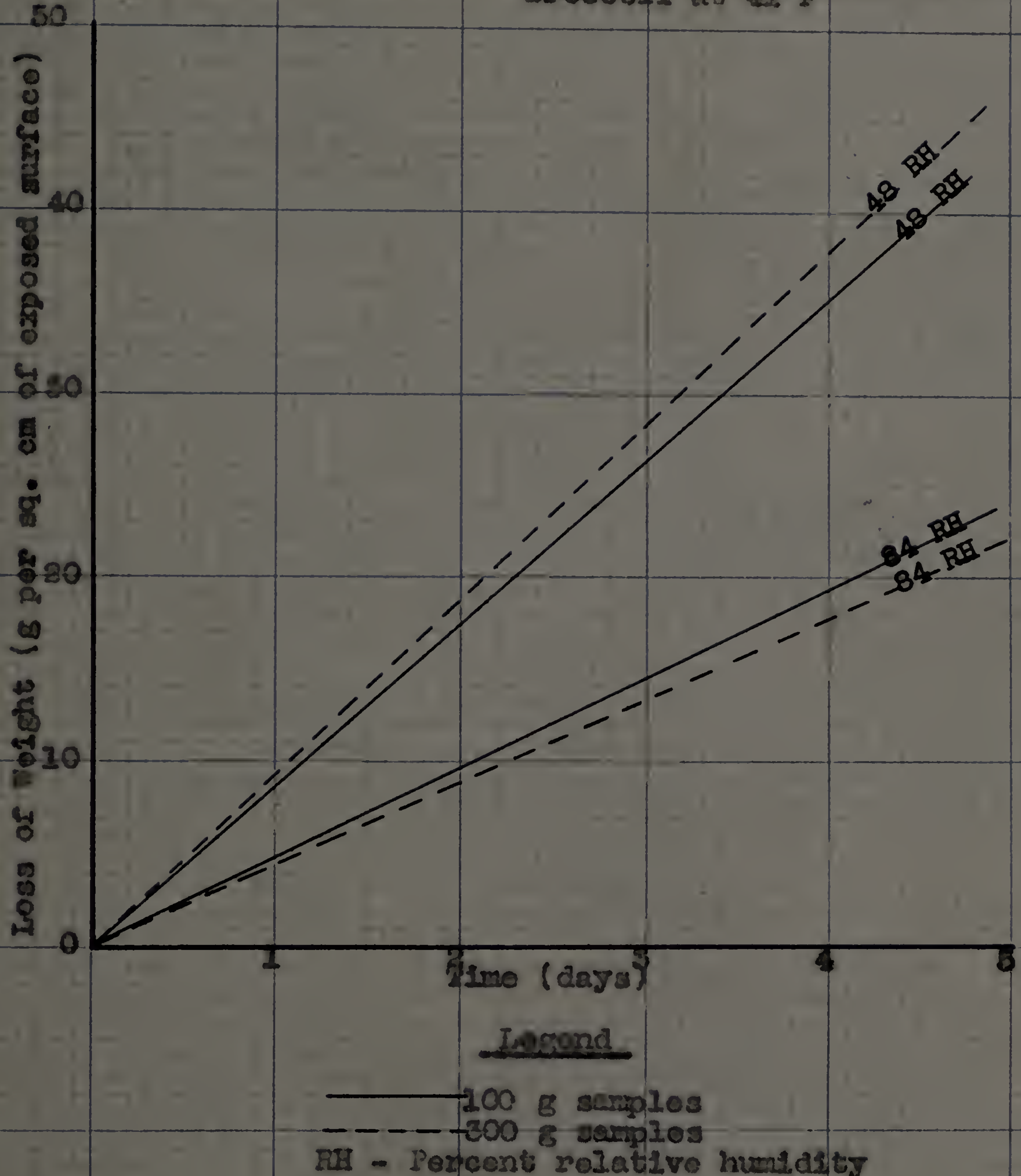


Figure 7. Effect of Size of Sample and Exposed Surface on Loss of Weight in Left-over Broccoli at 41°F



It was found that up to five percent loss in weight could occur without noticeable deterioration in appearance. From Figure 6 it may be observed that to prevent losses of moisture greater than five percent in four days, relative humidities of approximately 90 percent or higher are necessary.

Effect of Exposed Surface on Loss of Weight - To determine the effect of the size of sample and its exposed surface on the loss of weight, similar 100 and 300 gram samples, consisting of cooked broccoli and proportionate amounts of its cooking water, were stored in uncovered dishes of 187 and 520 milliliters capacity, respectively. The former was a small circular custard dish while the latter was a larger square ice-box dish. The custard dish was filled to the top while the other was only filled about half full.

The loss of weight per 100 square centimeters of exposed surface is shown in Table 8 and Figure 7. The data refer to the area of the open dish and not the actual area of the surface of the broccoli.

It is evident that the loss of weight was dependent on the area of the exposed surface rather than the size of the sample, type of dish or whether the evaporation surface is directly exposed to the atmosphere or is protected by the walls of the container.

Table 8. Loss of weight of left-over broccoli

	Days stored	1	3	4
Weight of sample	Relative humidity	Loss of weight per 100 sq. cm. of exposed surface		
grams	percent	grams	grams	grams
100	48	8.0	31.2	30.9
300	48	8.2	37.1	29.6
100	84	7.9	11.9	18.1
300	84	6.9	10.4	16.8

Deterioration of Organoleptic Qualities

The keeping quality of the vegetables at 41°F., as far as appearance, taste and aroma are concerned, was found to depend on the humidity of the storage atmosphere. In other words, the loss of tenderness, characteristic odor and flavor as well as discoloration ran parallel with the extent of dehydration.

Dehydration occurred only in the surface layers of the foods, the lower layers being of as good quality in all respects as the covered samples.

For simplification and purposes of comparison an attempt has been made in Table 9 to evaluate the quality of the different foods stored under the various conditions of humidity. Typical organoleptic observations made on peas are recorded in Table 10.

Table 9. Effect of humidity on quality of left-overs stored at 41° Fahrenheit

Relative humidity	Days stored 0	1	2	3	4	5
percent	score*	score*	score*	score*	score*	score*
			<u>Creamed mashed potatoes</u>			
100	100	100	100	--	80	80
65	100	90	80	--	40	--
55	100	80	70	--	--	20
51	100	80	80	--	20	--
42	100	80	70	--	--	20
			<u>Cooked frozen peas</u>			
100	100	--	100	--	100	100
65	100	70	50	--	0	--
55	100	--	50	--	--	0
51	100	70	40	--	0	--
42	100	--	50	--	--	0
			<u>Cooked frozen broccoli</u>			
100	100	100	100	--	90	80
84	100	100	90	--	80	--
75	100	90	90	--	70	--
62	100	90	80	--	60	--
59	100	90	80	--	60	--
55	100	80	70	--	--	0
42	100	80	70	--	--	0
			<u>Reheated canned snap beans</u>			
100	100	100	100	--	100	100
84	100	100	90	--	70	--
75	100	90	60	--	20	--
59	100	80	60	--	20	--
55	100	80	60	--	--	30
42	100	80	60	--	--	20

Table 9 (continued)

Relative humidity	Days stored 0	1	2	3	4	5
percent	score*	score*	score*	score*	score*	score*
			Sliced tomatoes			
100	100	100	100	100	100	--
84	100	100	80	--	--	0
80	100	80	80	70	20	--
65	100	70	40	30	0	--
62	100	80	40	--	--	0
55	100	80	60	--	0	--
42	100	80	70	--	0	--
			Radishes			
100	100	100	100	--	90	--
55	100	80	70	--	0	--
42	100	80	70	--	0	--

*		Score
* Original fresh sample	-	100
Spoiled	-	0

	Severe	Slight
Dehydration	-20	-10
Discoloration	-20	-10
Loss of tenderness	-20	-10
Loss of flavor	-20	-10
Loss of odor	-20	-10

Table 10. Organoleptic observations on left-over peas stored at 41°F.

Relative humidity percent	Days stored 1	2	4
	Aroma		
100	characteristic	characteristic	characteristic
65	faint pea odor	faint pea odor	dry hay odor
51	faint pea odor	faint pea odor	dry hay odor
	Color		
100	characteristic	characteristic	characteristic
65	slightly faded	slightly faded	black
51	slightly faded	slightly faded	black
	Dehydration		
100	none	none	none
65	surface dried	slightly shrivelled	badly shrivelled
51	surface dried	slightly shrivelled	badly shrivelled
	Tenderness		
100	tender	tender	tender
65	tender	less tender	very tough
51	tender	less tender	very tough
	Flavor		
100	characteristic	characteristic	characteristic
65	characteristic	slightly off	dry pea flavor
51	characteristic	off flavor	dry pea flavor

Storage of left-overs in covered containers, that is in an atmosphere saturated with water vapor, was found to result in least deterioration. All the vegetables tested, except sliced tomatoes, kept very well for at least four days at 100 percent relative humidity, whether stored in glass or oiled-silk covered dishes. At the end of four days the quality was practically as good as it was at the start of the test. Surface drying and discoloration were practically eliminated under these conditions.

Sliced tomatoes were found to keep well in covered dishes for two days but spoiled in four days.

Storage of left-overs in uncovered containers resulted in a loss of aroma, surface drying, discoloration and a loss in tenderness and flavor of the exposed surfaces at the end of four days. These changes were observed even at humidities as high as 84 percent, the highest humidity reached in refrigerator F.

At humidities between 42 and 60 percent, no significant organoleptic differences in the samples could be detected. Food stored at 65 percent relative humidity, however, showed on, and after the second day of storage, less discoloration, surface drying, etc. than did samples at 51 percent and lower humidities. When the humidities were raised to 84 and 62 percent this difference in quality was evident after the first day of storage. Up to 75 percent relative humidity, uncovered foods, although inferior to the corresponding covered samples, were of fair quality for one day or for two days at humidities of 75 to 84 percent.

Spoilage

From Table 11 it may be seen that it was apparently safe to store all left-overs, except sliced tomatoes, for at least four days in either covered or uncovered containers.

Only seven cases of spoilage were found in all the tests, six of which were tomatoes, the other was snap beans which spoiled in a covered dish after five days. Eighty-six percent of the spoilage cases occurred in foods stored in covered dishes.

Fifty percent of the sliced tomatoes in covered dishes spoiled inside of four days, one of these samples spoiling in only three days. Uncovered samples did not spoil even on six days' storage but they were badly dehydrated.

Loss of Vitamin C

The vitamin C (ascorbic acid) content of the various refrigerated foods is recorded in Table 12 and the percent loss of vitamin C during storage, in Tables 13 to 16.

Due to the wide variations in the rate of loss of vitamin C from different lots of the same vegetable, several determinations of the loss in one vegetable

Table 11. Spoilage of left-overs in four days at 39°-42°F. and 42-100 percent relative humidity

Left-overs	No. of tests	No. of cases of spoilage Covered dishes	Uncovered dishes
Creamed mashed potatoes	8	0	0
Peas	8	0	0
Broccoli	24	0	0
Snap beans	8	0	0
Radishes	4	0	0
Tomatoes	12	3	1

Table 12. Vitamin C content of left-overs stored at 39°-42°F.

Days	Percent relative humidity		
	100	55	42
	ascorbic acid*	ascorbic acid*	ascorbic acid*
	mg	mg	mg
		<u>Creamed mashed potatoes</u>	
0	0.20	0.20	0.20
1	0.13	0.14	0.12
2	0.07	0.09	0.06
5	0.04	0.04	0.04
	100	65	51
0	0.22	0.22	0.22
1	0.18	0.18	0.15
2	0.14	0.13	0.10
4	0.03	0.03	0.02
		<u>Cooked frozen peas</u>	
	100	55	42
0	0.36	0.36	0.36
1	0.24	0.21	0.22
2	0.17	0.15	0.16
5	0.13	0.11	0.11
	100	65	51
0	0.29	0.29	0.29
1	0.15	0.14	0.13
2	0.09	0.09	0.08
4	0.08	0.06	0.05

Table 12 (continued)

Days	Percent relative humidity 100 ascorbic acid*	55 ascorbic acid*	42 ascorbic acid*
	mg	mg	mg
	Reheated canned snap beans		
0	0.29	0.29	0.29
1	0.12	0.12	0.17
2	0.11	0.08	0.12
5	0.09	0.08	0.09
	100	75	59
0	0.28	0.28	0.28
1	0.19	0.21	0.22
2	0.16	0.18	0.18
4	0.21	0.22	0.20
	Scored radishes		
	100	55	42
0	1.80	1.80	1.80
1	1.10	0.72	0.77
2	0.94	0.62	0.73
4	1.62	1.39	1.53
	Sliced tomatoes		
0	0.80	0.80	0.80
1	0.67	0.65	0.54
2	0.65	0.61	0.47
4	1.20	1.00	1.41
	100	84	62
0	0.63	0.63	0.63
1	1.02	0.95	0.89
2	1.20	0.98	1.05
4	1.28	1.07	1.43
0	2.01	2.01	2.01
1	1.72	1.41	1.75
2	1.55	1.35	1.58
4	1.72	1.47	1.50

Table 12 (continued)

Days	Percent relative humidity		
	100	55	42
	ascorbic acid*	ascorbic acid*	ascorbic acid*
	mg	mg	mg
		Cooked frozen broccoli	
0	1.94	1.94	1.94
1	0.99	0.99	0.81
2	0.77	0.76	0.72
4	0.30	0.66	0.50
	100	75	59
0	3.48	3.48	3.48
1	2.36	2.65	2.91
2	1.60	1.77	2.36
4	1.86	2.38	1.90
	100	84	62
0	2.77	2.77	2.77
1	2.19	2.59	1.81
2	2.19	2.56	1.99
4	1.47	1.27	1.33
	100	75	55
0	5.38	5.38	5.38
1	4.86	4.10	3.86
2	4.23	3.50	3.31
4	2.62	2.79	2.75
	100	78	57
0	5.81	5.81	5.81
1	3.71	4.75	4.88
2	3.42	4.46	4.07
4	3.56	3.54	3.17

* Expressed as milligrams ascorbic acid per gram of vegetable on a dry weight basis.

(broccoli) stored at various humidities were made in order to obtain fair mean values.

Rate of Loss

From Tables 13 to 16 it appears that the rate of loss of vitamin C during the first day of storage is much greater than that occurring during the rest of the period. In broccoli for instance, at 100 percent relative humidity, 57 percent of all the vitamin C lost in 4 days was lost during the first day.

Figure 8 shows the vitamin C content of left-over broccoli, the shape of the curve being typical of those obtained for all the vegetables. The loss of vitamin C appears to be rapid for the first two days, after which the rate is much slower.

In only one day 20 to 60 percent of the vitamin C content of the foods tested was found to be lost at high or low humidities, while in four days the loss ran as high as 90 percent.

Effect of humidity on vitamin C loss

Figures 9 to 14 show the relationship between the loss of vitamin C and humidity during storage.

As can be seen from these curves, the vitamin C content of the vegetables was consistently greater at the higher humidities, the only exception being sliced tomatoes on the fourth day of storage.

Table 13. Percent loss of vitamin C of left-overs stored at 39°-42° Fahrenheit

Days		Percent relative humidity 100	65	51-55	42
		percent	percent	percent	percent
			Creamed mashed potatoes		
1		30	23	35	40
1		40	--	32	--
1		23	--	--	--
1		14	--	--	--
	Average	27	23	34	40
2		60	41	55	70
2		70	--	55	--
2		41	--	--	--
2		36	--	--	--
	Average	52	41	55	70
4		91	86	91	--
4		86	--	--	--
	Average	89	86	91	--
5		80	--	--	--
5		80	--	80	80
	Average	80	--	80	80
			Cooked frozen peas		
1		33	52	42	39
1		36	--	55	--
1		48	--	--	--
1		52	--	--	--
	Average	42	52	49	39
2		50	69	58	56
2		56	--	72	--
2		69	--	--	--
2		72	--	--	--
	Average	62	69	65	56
4		64	79	69	69
4		67	--	83	--
4		76	--	--	--
4		72	--	--	--
	Average	70	79	76	69

Table 14. Percent loss of vitamin C of left-overs stored at 39°-42° Fahrenheit

Days		Percent relative humidity			
		100	75	55-59	42
		percent	percent	percent	percent
			Reheated canned snap beans		
1		66	25	21	41
1		52	--	59	--
1		32	--	--	--
1		32	--	--	--
	Average	46	25	40	41
2		66	36	36	59
2		62	--	72	--
2		46	--	--	--
2		43	--	--	--
	Average	54	36	54	59
4		69	21	29	69
4		72	--	72	--
4		36	--	--	--
4		14	--	--	--
	Average	48	21	51	69
			Scored radishes		
1		40	--	60	57
1		38	--	--	--
	Average	39	--	60	57
2		48	--	66	59
2		47	--	--	--
	Average	48	--	66	59
4		16	--	23	15
4		5	--	--	--
	Average	11	--	23	15

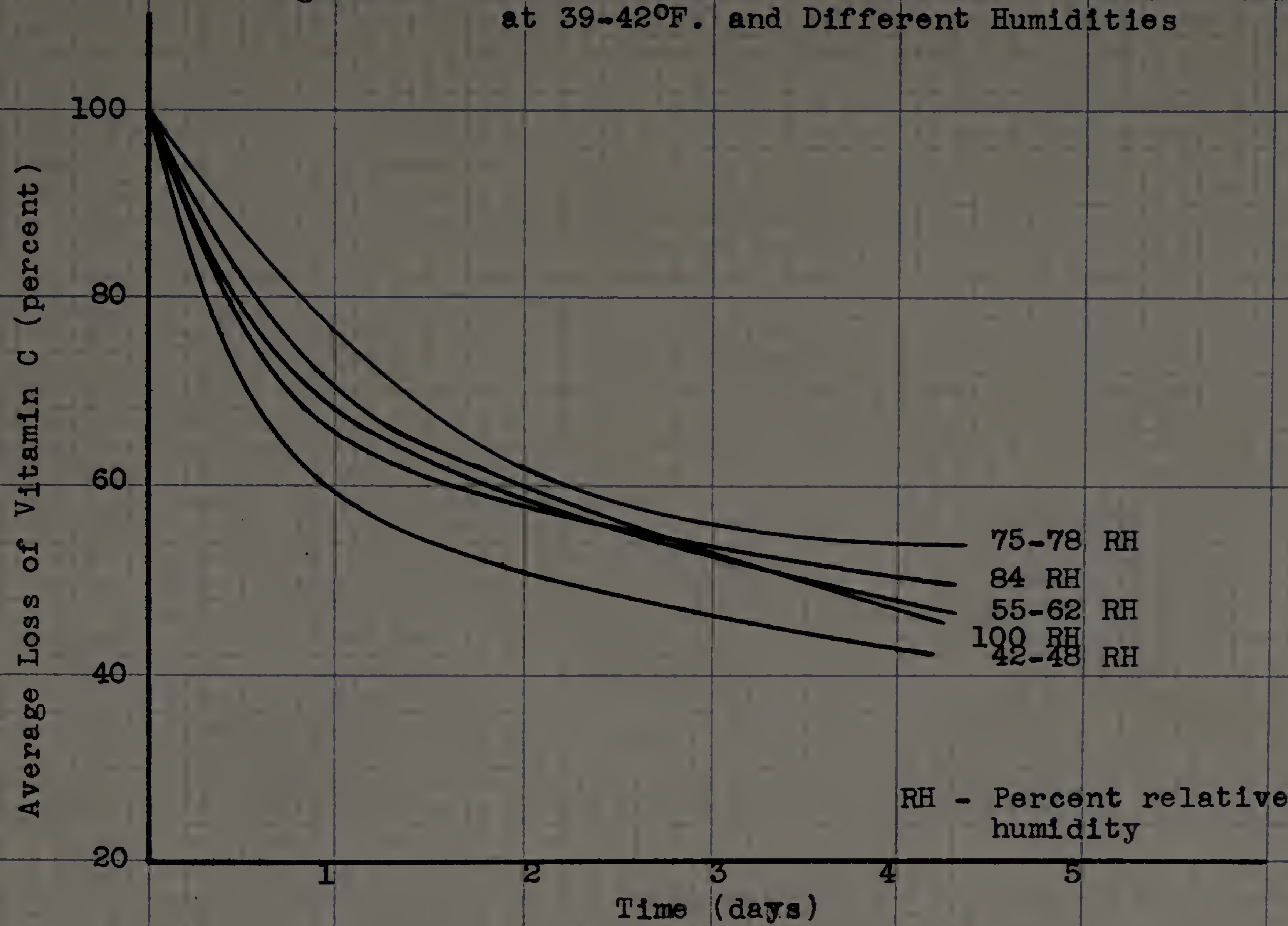
Table 15. Percent loss of vitamin C of sliced tomatoes stored at 39°-42° Fahrenheit

Days		Percent relative humidity 100	84	55-62	42
		percent	percent	percent	percent
1		23	+51	+41	33
1		10	30	13	--
1		+62	--	19	--
1		+62	--	--	--
1		15	--	--	--
1		14	--	--	--
	Average	+10	+10	+3	33
2		26	+56	+67	41
2		13	33	21	--
2		+105	--	24	--
2		+76	--	--	--
2		28	--	--	--
2		18	--	--	--
	Average	+16	+12	+7	41
4		+49	+70	+127	+76
4		+51	27	25	--
4		+122	--	--	--
4		+84	--	--	--
4		19	--	--	--
4		10	--	--	--
	Average	+46	+22	+42	+76

Table 16. Percent loss of vitamin C of left-over broccoli stored at 39°-42° Fahrenheit

Days		Percent relative humidity			
	100	84	75-78	55-62	42-48
	percent	percent	percent	percent	percent
1	39	7	18	35	58
1	59	52	24	16	31
1	24	46	24	49	46
1	41	40	29	28	48
1	37	29	23	16	42
1	5	--	--	49	--
1	5	--	--	--	--
1	15	--	--	--	--
1	37	--	--	--	--
1	35	--	--	--	--
Average	30	35	24	39	45
2	54	8	23	28	63
2	67	47	35	30	40
2	55	52	49	39	34
2	53	50	34	32	50
2	8	48	47	61	41
2	35	--	--	38	--
2	23	--	--	--	--
2	20	--	--	--	--
2	46	--	--	--	--
2	36	--	--	--	--
Average	40	41	38	38	46
4	82	54	39	52	74
4	84	30	48	45	42
4	43	61	32	49	57
4	50	50	52	66	60
4	54	57	57	52	52
4	40	--	--	--	--
4	55	--	--	--	--
4	48	--	--	--	--
4	49	--	--	--	--
4	28	--	--	--	--
Average	53	50	46	52	57

Figure 8. Effect of Humidity on Loss of Vitamin C in Left-Over Broccoli Stored at 39-42°F. and Different Humidities



Effect of Humidity on
Figure 9. Loss of Vitamin C in Left-over Creamed Mashed Potatoes stored at 39-42°F.

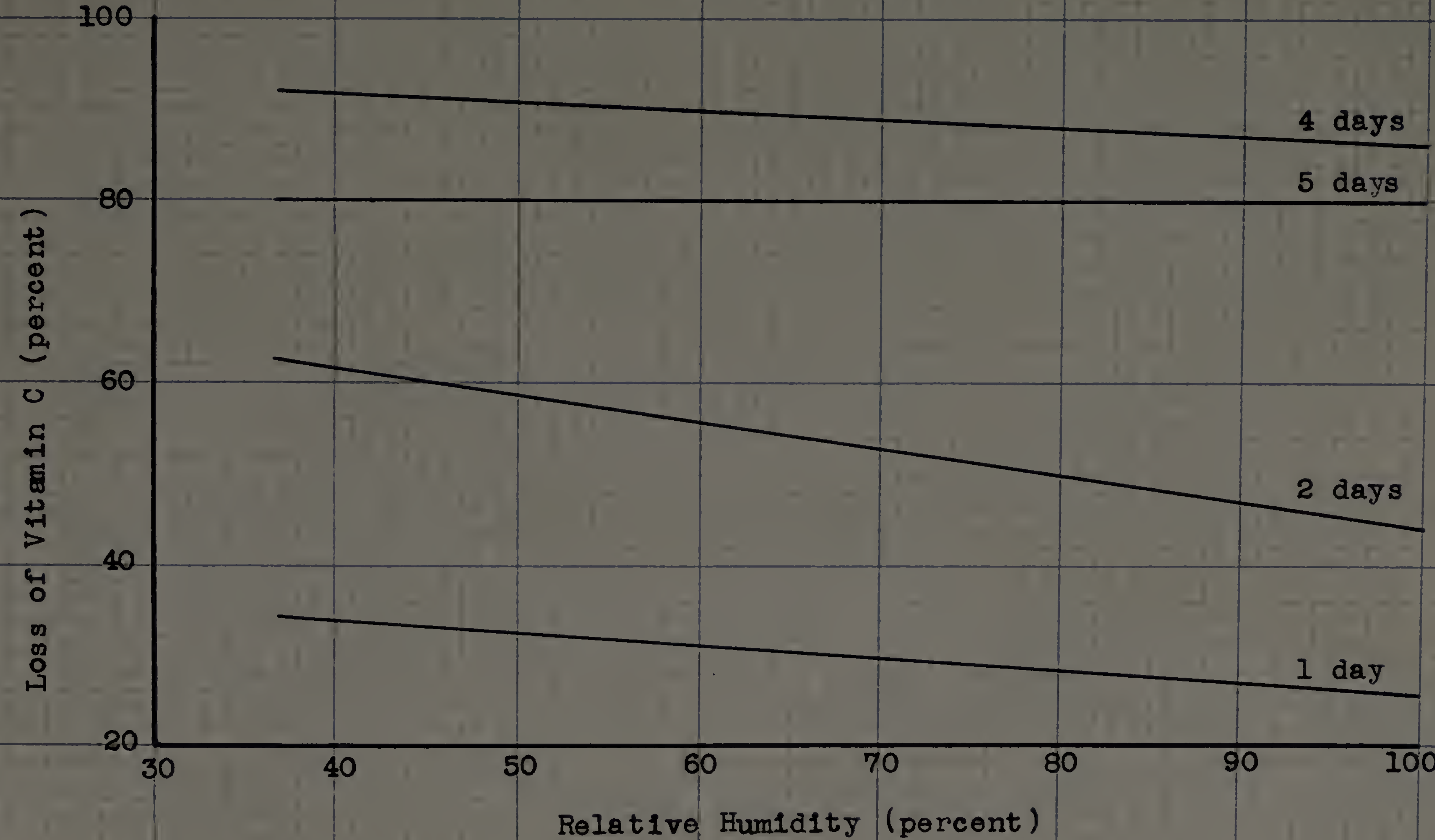


Figure 10. Effect of Humidity on Loss of Vitamin C in Left-over Peas Stored at 39-42°F.

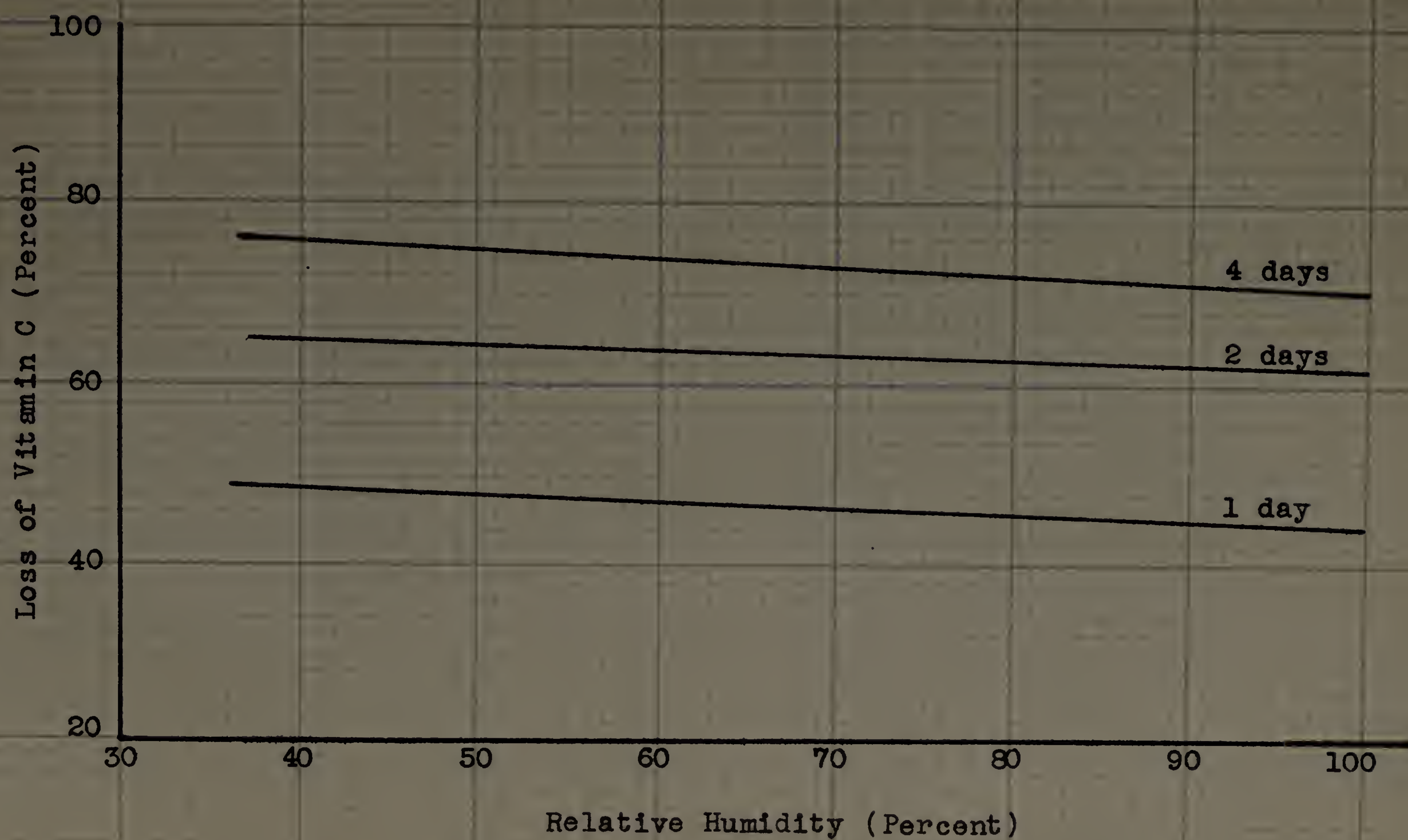


Figure 11. Effect of Humidity on Loss of Vitamin C in Left-over Snap Beans Stored at 39-42°F.

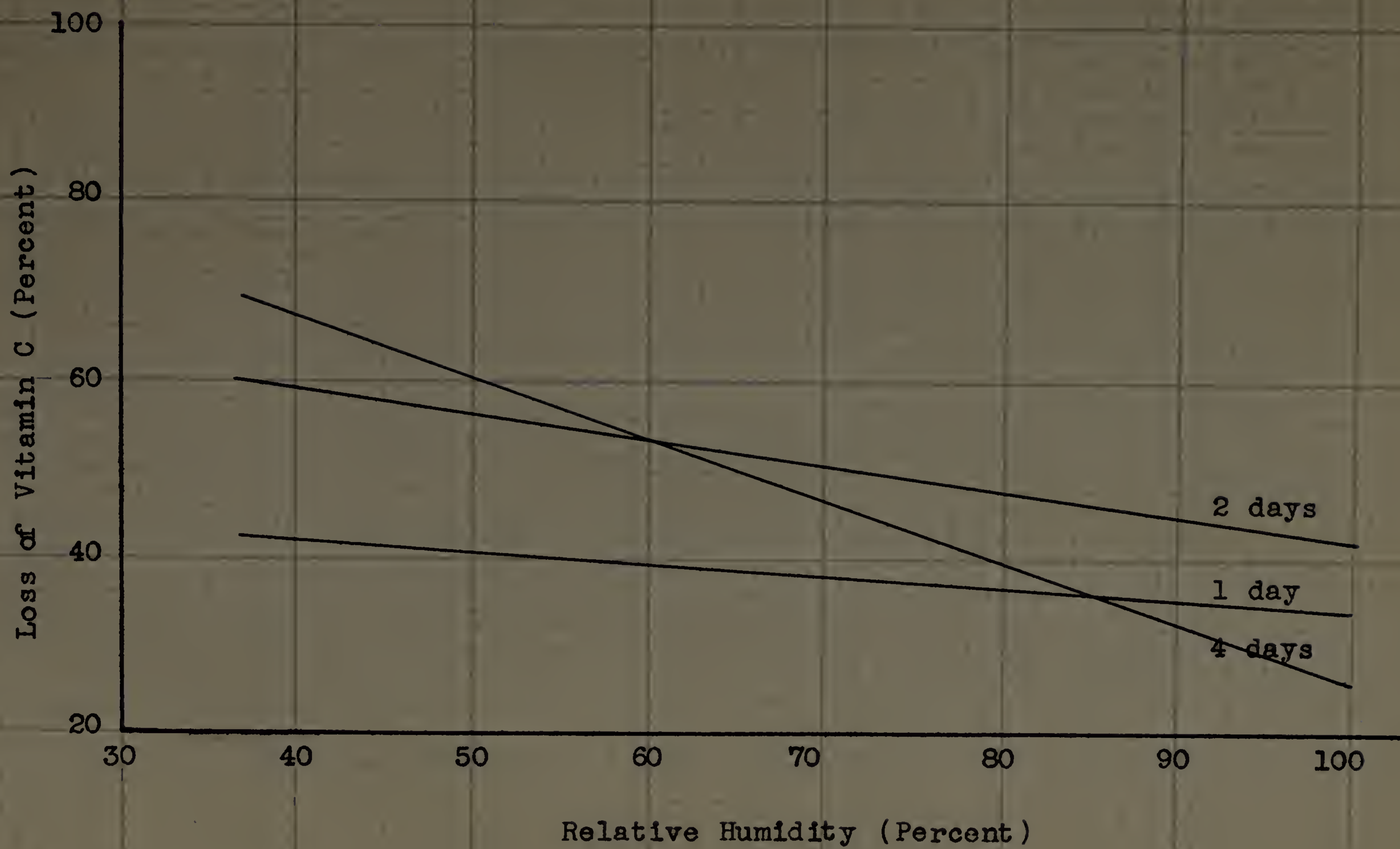


Figure 12. Effect of Humidity on Loss of Vitamin C in Left-over Radishes Stored at 39-42°F.

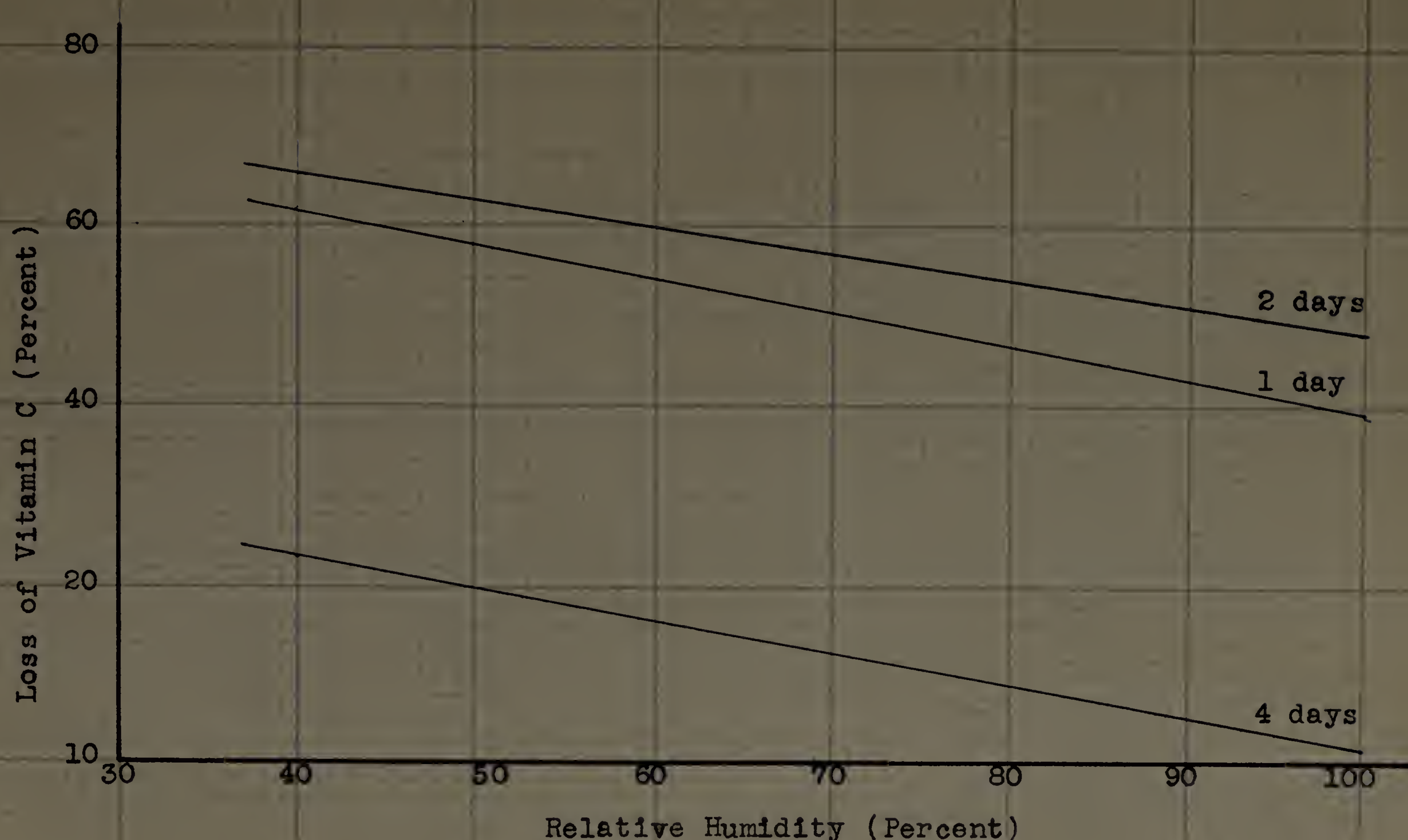


Figure 13. Effect of Humidity on Loss of Vitamin C in Left-over Sliced Tomatoes Stored at 39-42°F

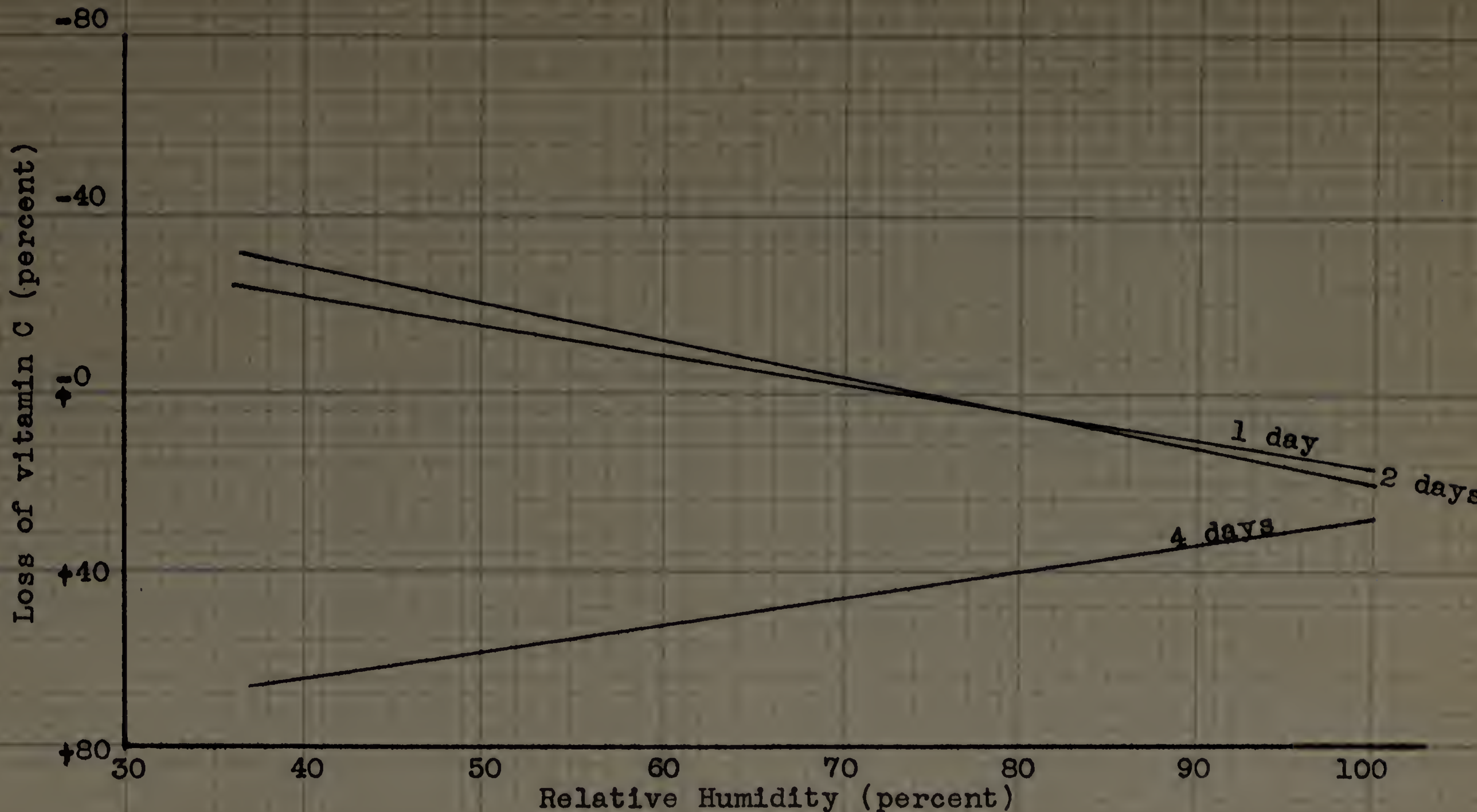
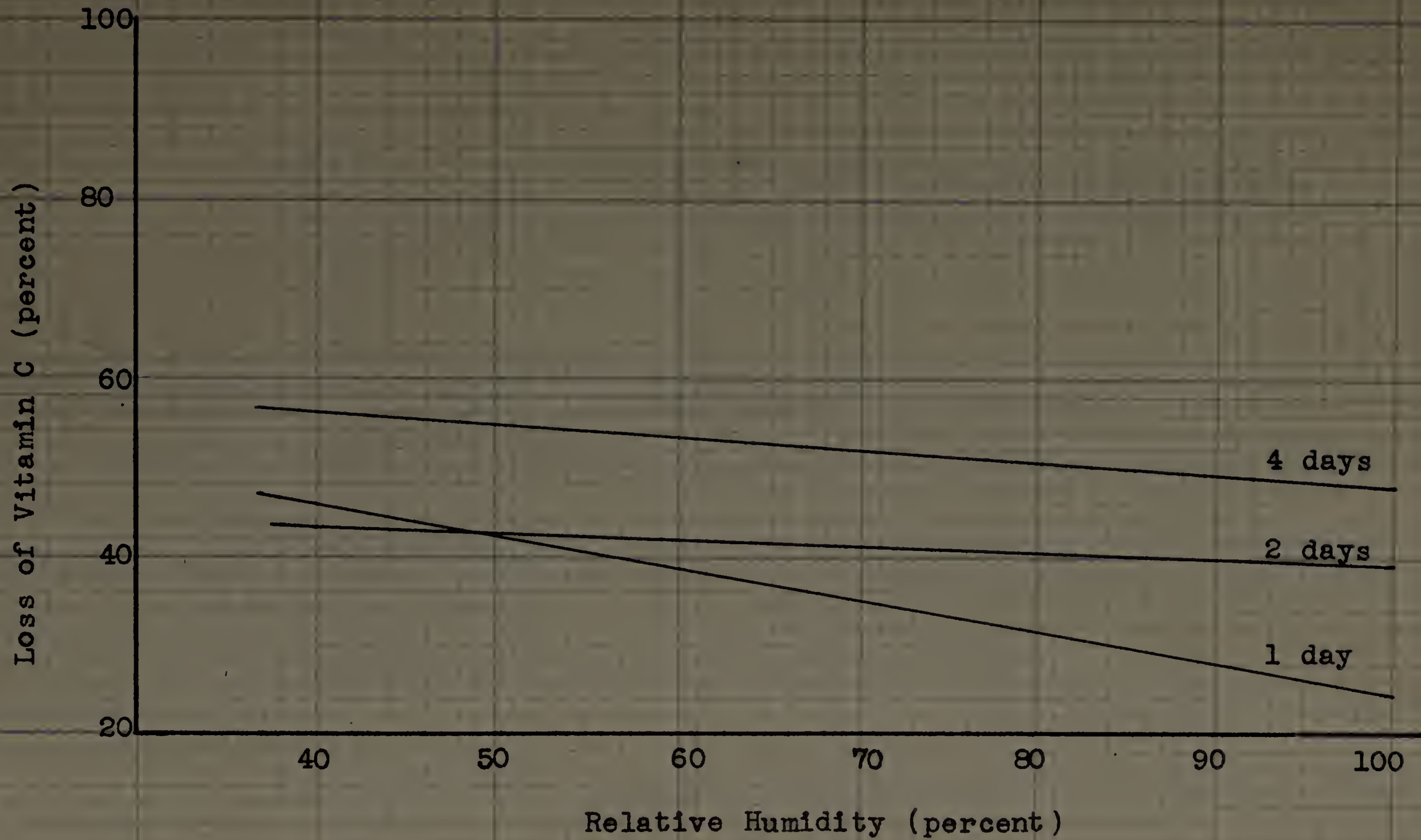


Figure 14. Effect of Humidity on Loss of Vitamin C in Left-over Broccoli Stored at 39-42°F.



Increase in vitamin C

Apparent increases in the vitamin C content during storage was found at times in snap beans, radishes, tomatoes and broccoli, no matter which method of sampling was used. From Table 17 it is seen most of the increases occurred toward the end of the test, that is, after a lapse of four days or so, while in one whole series (4 tests) the vitamin C content of the sliced tomatoes increased regularly with storage until, at the end of four days, the titratable ascorbic acid content was from 70 to 127 percent above the original.

Preliminary bacterial counts were run in conjunction with the ascorbic acid determinations to see if these increases could possibly be due to the growth of microorganisms, but no correlation was found to exist in the few tests made.

Vitamin C content of juices of left-overs

Any decrease of the vitamin C content of creamed mashed potatoes, sliced tomatoes, and radishes was probably due to oxidation. In the case of the vegetables such as broccoli, which were stored with their juices, the question arises as to whether or not some of the ascorbic acid was dissolved out of the vegetable by the juices during storage.

In Table 18 it may be seen that the vitamin C content of the vegetable itself gradually fell as usual.

Table 17. Number of times apparent increases in vitamin C occurred

Left-over	No. of tests run	No. of tests showing apparent increase in vitamin C	Time when increase occurred
Broccoli	20	6	4 at 4th day 2 at 6th day
Snap beans	8	4	4 at 4th day
Tomatoes	12	11	7 at 4th day 4 at 1st day (increase continued to end of test on 4th day
Radishes	4	4	4 at 4th day

Table 18. Vitamin C content of left-over broccoli and its juice stored at 41-42°F.

Relative humidity	Storage period (days) 0	1	2	4	Storage period (days) 0	1	2	4
	ascorbic acid per gm. broccoli*				ascorbic acid per ml. juice			
	mg	mg	mg	mg	mg	mg	mg	mg
100	5.81	3.78	3.71	4.16	0.47	0.46	0.47	0.49
78	5.81	4.75	4.46	3.54	0.47	0.49	0.40	0.42
57	5.81	4.88	4.07	3.17	0.47	0.53	0.45	0.43
100	5.38	4.60	4.30	2.79	0.49	0.58	0.45	0.35
75	5.38	4.10	3.50	3.69	0.49	0.55	0.49	0.38
55	5.38	3.86	3.31	2.75	0.49	0.55	0.48	0.37

* ascorbic acid calculated on a moisture-free basis.

Table 19. Comparison of percent loss of vitamin C in left-over broccoli and left-over broccoli plus juice stored at 39-42° Fahrenheit

Days	Percent relative humidity 100	78	57
	percent	percent	percent
		Broccoli	
1	35	18	16
2	36	23	30
4	28	39	45
		Broccoli plus juice	
1	21	18	15
2	22	19	27
4	17	37	46

The vitamin C content of the juice, however, usually increased during the first day or two and then decreased. Thus, it is evident that some of the loss of the vitamin C of the vegetable was due to its removal by the surrounding juices.

From Table 19 it is shown that the total loss of vitamin C from the vegetable plus juice was slightly less than the loss from the vegetable alone. This difference diminished with the length of storage period.

Discussion

The large amount of weight found to be lost in uncovered containers of food in a comparatively short time is in agreement with the findings of Harris and Mosher (1941) on the loss of weight of lettuce during refrigeration. The need of covering refrigerated foods is appreciated when it is considered that in only two days one-tenth of the weight of your food has evaporated into the air.

Considerable attention has been paid to this dehydration of foods in commercial cold storage, because a loss in weight means a loss of money. In home refrigeration the drying-out of the surfaces of the food and loss in quality are of primary importance.

The vegetables stored with juice lost approximately the same amount of weight as those without. It therefore seems probable that most of the evaporation occurred on the surfaces of the vegetables. In cases where juice was present, the vegetables probably acted as a wick. This seems reasonable when the large surface of the exposed vegetables as compared to that of the liquid is considered.

It should be noted that even at humidities of 80 to 84 percent there is as much as 10 percent loss of weight in four days. It was therefore found advisable to cover all foods, even in a high humidity type of refrigerator.

These tests were run in the winter months during which it was found impossible to obtain a higher humidity than 84 percent in the high humidity type of refrigerator. In warm weather when more moisture is in the air, higher humidities may be obtained. However, storing left-overs in uncovered dishes in a refrigerator which maintains proper storage conditions for only part of the year can hardly be recommended.

Besides preventing a loss in weight, covered dishes best preserved the organoleptic qualities and vitamin C content of the foods. The 100 percent relative humidity did seem to favor spoilage more than the lower humidities. However, few left-overs would never be stored longer than four days. This period was found perfectly safe for all the foods tested, except sliced tomatoes, which kept well for only two days.

The better retention of vitamin C at high humidities is in agreement with the work done by Harris, Wissmann and Greenlie (1939).

As dehydration and loss of vitamin C were both inversely proportional to the humidity, it is conceivable that the greater losses of ascorbic acid, at the low humidities, might be due to the transportation of ascorbic acid to the exposed surfaces of the vegetables by the evaporating water. Hence greater oxidation of ascorbic acid due to its exposure to air could take place.

Large variations in the vitamin C content of the same vegetable stored under identical conditions are also found in the data of these authors. They too recorded increases in the vitamin C content of fresh peas, lima beans, spinach, and lettuce, on the seventh day of storage.

Plausible reasons for this apparent increase in vitamin C content would appear to be - formation of some substance which reduces the indophenol dye, sampling, or production of ascorbic acid, either by ripening processes or its synthesis by microorganisms. As stated previously, changing the method of sampling did not eliminate these increases.

Microorganisms have been known to synthesize vitamin C or vitamin C-like substances. Bacterium prodigiosus was found by Berenesi and Illĕngi (1938) to produce ascorbic acid from carbohydrates, especially d(+)xylose while Hermann and Foder (1935) showed the presence of ascorbic acid among the products obtained by growing "Kombacha", a symbiotic association of bacteria and yeasts, in a glucose cane sugar medium.

Isakova (1940) reported bacteria of the Azobacter genus increased the vitamin C synthetic activity of seeds during germination. Tikha and Heino (1941) found compressed yeast contained vitamin C and that the ascorbic acid concentration of fruit juices was higher when fermented than when unfermented.

The reduction of dehydroascorbic to ascorbic acid by Crookes strain of Bacillus coli was reported by Esselen and Fuller (1939).

Fox and Stone (1937) found a reducing substance in Kaffir beer similar to ascorbic acid but which had no anti-scorbutic activity. Aspergillus niger was reported by Novotel and Vodova (1937) and Bernhauer, Görlick and Kocher (1936) to produce substances which like ascorbic acid, reduced 2,6-dichlorophenolindophenol dye. Several species of Aspergillus and Penicillium molds produced a reducing substance to a marked degree according to Fukumoto and Shimomura (1937). Japanese tea fungus was also found to produce a substance of this nature. (Kasheonik, 1937).

Ripening could not cause the increase in vitamin C in the cooked broccoli or the snap beans. It is a possibility, however, in the radishes and sliced tomatoes. Clow and Marlatt (1930) and House, Nelson and Haber (1939) reported the vitamin content of tomatoes increased during the ripening process. Kraus, Washbourn and Hoffman (1937) reported the vitamin C was reduced slightly during ripening but increased rapidly during the final softening. Maclinn and Fellers (1938), however, found the degree of ripeness did not affect the amount of vitamin C in tomatoes.

Increases of vitamin C during ripening were also reported by Robinson (1927) in the case of pau-paus and by Harris and Poland (1939) for bananas. Guthrie (1937) found the vitamin C content of old potatoes could be doubled in two days by cutting into thin slices and storing in moist air.

PART D - REFRIGERATION OF FROZEN FOODS

Experimental Procedure

Frozen broccoli, peas, spinach and peaches of two different, nationally known brands (B and D) were stored at various temperatures in refrigerator G for as long as one week, on the middle shelf of the box and lower shelf of the freezing compartment. The packages were left sealed until tested for loss of quality by organoleptic observations, loss of weight, pH value and vitamin C determinations.

As there was no significant change found in the moisture content during storage, the ascorbic acid was calculated per 100 grams of fresh vegetable, rather than on a dry weight basis.

Different methods of defrosting frozen foods were compared. The packages were opened and left loosely covered at room temperature and in the refrigerator at various temperatures until thawed. Thawing was also accomplished by heating the frozen vegetables in a container on a steam bath until the last ice crystal had disappeared. Tests for quality were also run on these samples.

During the tests, household conditions of refrigerator load and door openings were maintained.

Presentation of Results

The temperatures recorded are the average temperatures of the surrounding air, not the temperature of the foods themselves. For instance in defrosting at room temperature, the temperature of the frozen food, when completely thawed, was still far below the room temperature of 75° or 80°F.

In the freezing compartment when the average temperature of the air was found to be 16°F. the average temperature of the foods stored there was only 14°F. while at 25°F. air temperatures, the foods averaged 23°F.

Storage

Change in pH value

Very little change in pH value took place in frozen foods stored at 16° to 82°F., the greatest change being only 0.6 pH units, when the peas soured. The pH value did not give reliable indication of spoilage, however, as in one instance when a sample of broccoli spoiled in seven days at 42°F. yet only showed an increase in pH value of 0.1 units.

The maximum variation in pH value, where spoilage did not occur, was only 0.3 units.

Loss of weight

There was no loss of weight in any of the samples at any temperature except in one sample of peaches which lost four percent of its weight in seven days at 42°F. due to leakage of syrup.

Deterioration in organoleptic quality

There was no noticeable deterioration in any organoleptic quality of the frozen foods stored at 16° or 25°F. for seven days except for a very slight darkening of the surfaces of frozen peaches stored at 25°F. There was also a slight amount of free liquid present after seven days at this temperature. The ice crystals inside the foods increased in size at both 16° and 25°F., but no difference in texture could be found on thawing.

Some dehydration of the frozen foods occurred as shown by the growth of ice crystals on their surfaces. However, this did not affect the quality.

Storage of frozen foods at 35° and 42°F. did cause a slight deterioration in quality when stored for seven days, but up to one day, by which time all the samples had thawed, no changes could be observed except in the case of peaches at 42°F., which darkened slightly on their surfaces.

In seven days the peaches stored at 42°F. had become badly discolored, especially in the surface layers. Only about 25 percent of the slices, those in the very middle of the package, were not oxidized. The remainder turned a dirty brown, in some cases clear through the slice. All the other vegetables of one brand were also noticeably discolored in seven days at 35° or 42°F., while the other brand retained its color very well. Both brands developed slight off-flavors, however.

Spoilage

Of the four tests run at 35°F. none of the frozen foods spoiled, while out of eight samples stored at 42°F. for seven days two samples spoiled (peas and broccoli), both of the same brand.

Loss of vitamin C

From Tables 20 and 21 it is seen that loss of vitamin C of frozen vegetables, if kept frozen between 16° and 25°F., is negligible in one day and in seven days at 16°F., with one exception. However, the vitamin C loss was quite high after seven days at 25°F.

Storage at 35° to 42°F., which allowed thawing to take place, resulted in greater losses in seven days. The losses occurring even in one day at these temperatures were considerable.

Peaches lost more vitamin C on storage than the vegetables, a rapid loss taking place even at 25°F.

Often storage at room temperature for only five hours resulted in losses of vitamin C equal to or more than those taking place in seven days at 25°F. or one day at 42°F.

Above 16°F. the rate of loss of vitamin C appeared to increase rapidly with the temperature, a great increase occurring at and above the melting point.

Table 20. Change in vitamin C content of frozen foods during storage

Temperature	Brand	Storage period: 0 day ascorbic acid*	0 day loss	5 hrs. ascorbic acid*	5 hrs. loss	1 day ascorbic acid*	1 day loss	7 days ascorbic acid*	7 days loss
°F.		mg	percent	mg	percent	mg	percent	mg	percent
				Broccoli					
16	B	45.4				44.9	1	48.2	+6
16	D	32.1				29.0	10	36.2	+13
Average							6		+10
25	B	73.0				71.5	2	62.0	15
25	B	88.1						73.5	17
25	B	97.4						73.5	25
25	D	63.0				61.0	3	51.3	19
25	D	62.6						49.2	21
25	D	64.1						48.6	24
Average							2		20
35	B	45.4				42.9	6	27.8	39
35	D	32.1				20.4	36	12.3	62
Average							21		51
42	B	73.0				69.3	5	32.0	56
42	D	63.0				72.4	+15	0.8	99**
Average							+5		78
74	B	73.0		58.3	20				
74	B	45.4		57.4	+26				
74	D	63.0		62.7	0				
74	D	32.1		45.3	+41				
Average					+12				

Table 20 (continued)

Temperature	Brand	Storage period: 0 day ascorbic acid*	0 day loss	5 hrs. ascorbic acid*	5 hrs. loss	1day ascorbic acid*	1day loss	7 days ascorbic acid*	7 days loss
°F.		mg	percent	mg	percent	mg	percent	mg	percent
					Spinach				
16	B	20.3				20.4	0	29.7	+46
16	D	21.8				20.2	7	5.6	74
Average							4		14
25	B	18.0				17.9	0	19.8	+10
25	D	18.0				17.1	5	13.7	24
Average							3		7
35	B	20.3				13.2	35	18.9	7
35	D	21.8				5.7	74	6.5	70
Average							55		39
42	B	18.0				23.7	+32	13.1	27
42	D	18.0				9.6	47	6.3	65
Average							8		46
76-79	B	18.0		32.9	+83				
76-79	B	20.3		14.8	27				
76-79	D	18.0		15.4	14				
76-79	D	21.8		13.2	39				
Average					0				
					Peaches				
25	B	2.4				2.2	8	1.4	42
25	D	2.5				2.0	20	1.0	60
Average							14		51
42	B	2.4			(7 hrs)	1.8	25	1.3	46
42	D	2.5			(7 hrs)	0.9	64	0.8	68
Average							45		57
74	B	2.4		0.8	67				
74	D	2.5		0.8	68				
Average					68				

Table 20 (continued)

Temperature	Brand	0 day ascorbic acid*	0 day loss	5 hrs ascorbic acid*	5 hrs loss	1 day ascorbic acid*	1 day loss	7 days ascorbic acid*	7 days loss
°F.		mg	percent	mg	percent	mg	percent	mg	percent
				Peas					
25	B	19.2				18.0	6	10.5	45
25	D	16.0				14.1	12	5.5	66
Average							9		56
42	B	19.2				15.5	19	8.1	58
42	D	16.0				9.7	39	1.4	91**
Average							29		75
82	B	19.2		15.5	19				
82	D	16.0		11.1	31				
Average					25				

* Ascorbic acid calculated per 100 grams of food.
** Spoiled.

Table 21. Average loss of vitamin C of frozen foods during storage

Temperature	Storage period									
	5 hrs.	7 hrs.	1 day				7 days			
°F.	74-82	42	16	25	35	42	16	25	35	42
	Percent loss of ascorbic acid									
Broccoli	+12	--	5	2	21	+5	+10	20	51	78
Spinach	0	--	4	3	55	8	14	7	39	46
Peas	25	--	-	9	--	29	--	56	--	75
Average	4	--	5	5	38	11	2	28	45	66
Peaches	68	45	14					51		57

Defrosting

Rapid and slow methods of defrosting were used to determine their effects on the quality of the foods.

Complete thawing took place in vegetables in 24 hours at 35° to 42°F. while peaches required only seven hours. At a room temperature of approximately 80°F. thawing was completed in five hours in all cases whereas seven minutes were needed in defrosting on a steam bath.

Organoleptic quality

No difference in organoleptic qualities could be attributed to the method of defrosting.

Change in pH Value

The pH value of the foods was not noticeably affected by defrosting, and never amounted to over 0.3 pH units.

Loss of vitamin C

The losses of vitamin C caused by the different methods of defrosting are recorded in Tables 22 and 23. As can be seen the results were very inconsistent.

Considerable losses of vitamin C were found to occur in peaches whether defrosting took place slowly at low temperatures or rapidly at high temperatures. The losses at high temperatures were near 70 percent while defrosting at 42°F. reduced it to 45 percent.

The vegetables lost less vitamin C in defrosting than the peaches. Brand B in most cases contained more

Table 22. Loss of vitamin C during defrosting of frozen foods

Food	Defrosting conditions	Brand	Ascorbic acid* original	Ascorbic acid* final	Loss vitamin C
			mg	mg	percent
Broccoli	24 hours at 35°F.	B	45.4	42.9	6
		D	32.1	20.4	36
	24 hours at 42°F.	B	77.5	73.5	5
		D	60.9	70.3	+15
	5 hours at 74°F.	B	77.5	61.8	20
		B	45.4	57.4	+26
		D	60.9	61.2	0
		D	32.1	45.3	+41
	7 min. on steam bath	B	63.0	48.0	24
		B	45.4	44.8	1
		D	73.0	37.3	49
		D	32.1	39.3	+22
Peas	24 hours at 42°F.	B	19.2	15.5	19
		D	16.0	9.7	39
	5 hours at 82°F.	B	19.2	15.5	19
		D	16.0	11.1	31
	7 min. on steam bath	B	19.2	18.2	5
		D	16.0	12.7	21
Spinach	24 hours at 35°F.	B	20.3	13.2	35
		D	21.8	5.7	74
	24 hours at 42°F.	B	18.0	23.7	+32
		D	18.0	9.6	47
	5 hours at 76°-79°F.	B	18.0	32.9	+83
		B	20.3	14.8	27
		D	21.8	13.2	39
		D	18.0	15.4	14
	7 min. on steam bath	B	18.0	11.1	38
		B	20.3	13.9	32
		D	18.0	18.3	+2
		D	21.8	13.4	39

Table 22 (continued)

Food	Defrosting conditions	Brand	Ascorbic acid* original	final	Loss vitamin C
			mg	mg	percent
Peaches	7 hours at 42°F.	B	2.4	1.8	25
		D	2.5	0.9	64
	5 hours at 74°F.	B	2.4	0.8	67
		D	2.5	0.8	68
	7 min. on steam bath	B	2.4	0.6	75
		D	2.5	1.1	56

* ascorbic acid calculated as milligrams per 100 grams of fresh food.

Table 23. Average loss of vitamin C during defrosting

Food	Method of defrosting			
	24 hours at 35°F.	24 hours at 42°F.	5 hours at 74-82°F.	7 minute steam bath
	Loss of vitamin C (percent)			
Broccoli	21	+5	+11	13
Peas	--	29	25	13
Spinach	55	8	0	27
Average	38	11	5	18
Peaches	--	45	68	66

ascorbic acid at the start and lost less on storage than brand D under the same conditions.

Discussion

The necessity of keeping frozen foods at 16°F. or lower, even for short periods of time, to prevent excessive losses of vitamin C is in agreement with work reported by Jenkins, Tressler and Fitzgerald (1938).

Berry (1937) found that thawed peas spoiled in three to four days at 40°F. Most producers warn against keeping thawed frozen foods, even in a refrigerator, for over 24 hours. In the present investigation no more spoilage was found in the defrosted foods when stored for one week than would be expected in similar left-over foods. Spoilage as well as the amount of vitamin C lost seemed to depend on the brand of food, that is, on the freezing process and care in handling.

The loss of vitamin C of peas by defrosting is contrary to the finding that none is lost when thawed at room temperature (Jenkins, Tressler and Fitzgerald, 1938, and Fenton and Tressler, 1938A). Fellers and Stepat (1935) reported a loss of 70 percent of vitamin C during defrosting of peas at room temperature from two to six hours. This is a much higher loss than was observed in the present work. The vitamin C losses noted in defrosting spinach were much higher than those reported by the U. S. Dept. Agric. (1939).

These differences may be due to the extent to which the enzymes have been inactivated. Likewise the large loss of vitamin C found in peaches may be due to the fact that their enzymes had not been inactivated by sufficient blanching as is done in freezing vegetables.

It is evident that vegetables should not be defrosted by any means until actually cooked, while the best method of defrosting peaches appears to be in the refrigerator.

PART E - EFFECTS OF AIR MOVEMENT AND HUMIDITY ON FLAVOR TRANSFER AND AIR-BORNE CONTAMINATION

Experimental Procedure

Flavor transfer

Canned crab meat and salt codfish were used as contaminating substances while unsalted creamery butter and processed cream cheese were used as flavor absorbers.

The flavor emitters were stored on the middle shelf of each refrigerator while the absorbers were placed in corresponding positions on the bottom shelf. Uncovered and covered dishes of various types were used for storage of the butter and cheese. Samples were compared periodically for flavor, between themselves and with a control.

The rate of flavor transfer in the two boxes was also compared by chemical means. One petri dish containing 50 ml. of five percent acetic acid was placed on the middle shelf of each refrigerator. Petri dishes of uniform size, containing 25 ml. of freshly distilled water were then placed on each of the three shelves in both boxes.

Samples were removed periodically and titrated with one normal sodium hydroxide to determine the amount of acid absorbed by the water.

A similar test was run using ordinary refrigerator jars with various types of covers.

In all these tests the doors of the refrigerators were opened a normal number of times each day and a medium size load kept in the boxes. Activated charcoal was removed from a filter present in refrigerator G so that it would not interfere with the test.

Air-borne contamination

Nutrient agar plates were exposed in both boxes for verying lengths of time. A normal food load was present in each box, while the tests were run both with and without door openings.

Presentation of Results

Flavor Transfer

Table 24 shows that uncovered cheese and butter picked up more flavors when stored under conditions of low humidities and considerable air movement than at high humidities and restricted air movement. Even glass covered dishes did not prevent flavor transfer. The worst flavors occurred in the samples stored in refrigerator G.

Butter wrapped in parchment and cream cheese rewrapped carefully in its original carton absorbed no more flavors than when stored in glass covered refrigerator dishes. Oiled silk covers were found to permit the transfer of flavor to butter. In this case, a bad off-flavor

Table 24. Effect of humidity and air movement on flavor transfer at 41°F.

Storage conditions	Storage period: 24 hours, butter flavor	24 hours, cheese flavor	48 hours, butter flavor	48 hours, cheese flavor
Refrigerator F 84 percent relative humidity, slight air movement (uncovered dishes)	bad	bad	bad+	bad+
Refrigerator G 65 percent relative humidity, considerable air movement (uncovered dishes)	bad+	bad+	bad++	bad++
Glass covered dishes in refrigerator F	none	none	slight	slight
Glass covered dishes in refrigerator G	slight	none	slight+	slight+
Oiled silk covered dishes in refrigerator G	slight+		bad	
Original wrapping in refrigerator G	slight	none	slight	slight+
Sealed jars in refrigerator G	none		none	

developed in 48 hours which was much worse than the samples in glass covered jars but not as bad as the uncovered samples.

Sealed jars were the only containers which offered protection against the absorption of flavor.

No absorption of acetic acid by water in glass or oiled silk covered dishes could be detected by titrating with sodium hydroxide.

The chemical measurement of the flavor transfer as recorded in Table 25 confirms the organoleptic findings concerning the two refrigerators. The rate of flavor ta transfer in refrigerator G was 50 percent greater than in refrigerator F.

The same absorption of acetic acid occurred on the middle and bottom shelves of both refrigerators.

Storage on the top shelf of refrigerator G resulted in the least absorption of flavor while on the top shelf of refrigerator F, the absorption was greatest.

<u>Air-borne Contamination</u>

Table 26 reveals that there was no significant difference in the amount of air-borne contamination in the two refrigerators.

Very few organisms were deposited on a given surface when the doors were left closed, while door openings resulted in much more contamination.

Table 25. Influence of positions on flavor absorption in domestic refrigerators

Hours stored	2	19	44	73
NaOH (1N.) required to neutralize acetic acid absorbed				
	ml	ml	ml	ml
Refrigerator F				
Top shelf	0	0.18	0.29	0.52
Middle shelf	0	0.16	0.27	0.34
Bottom shelf	0	0.14	0.24	0.38
Average	0	0.16	0.27	0.41
Refrigerator G				
Top shelf	0	0.12	0.27	0.37
Middle shelf	0	0.34	0.52	0.69
Bottom shelf	0.09	0.38	0.47	0.65
Average	0.03	0.28	0.42	0.57

Table 26. Number of bacteria and mold colonies on nutrient agar plates exposed in refrigerators

Refrigerator	Exposure time	Door openings	No. of colonies	Mean
	hours			
F - 41°F., 82 percent relative humidity, slight air movement	1.5	none	0	
			1	1
	13.5	none	0	
			4	2
	1.5	6	6	
			3	5
	13.5	19	14	
			12	13
G - 41°F., 63 percent relative humidity, considerable air movement	1.5	none	0	
			1	1
	13.5	none	1	
			4	3
	1.5	6	11	
			3	7
	13.5	19	3	
			10	7

Discussion

The greater amount of flavor transfer at low humidities and considerable air movement than at high humidities and restricted air movement was in agreement with the findings of Crocker (1941) as was also the fact that sealed covers were found necessary for complete protection.

The obvious solution to the problem of odor transfer in a refrigerator is to eliminate the source of contamination through proper storage methods. The other foods then could be safely covered with whatever type of covers were available.

The greater flavor transfer by relatively greater air velocity is understandable. The effect of humidity on odor transfer is due entirely to its effect on the rate of dehydration of the odor producing substance, according to Crocker (1941). He found the evaporation of odor or flavor was proportional to the evaporation of moisture, that is the flavor transfer was due to a so-called low temperature steam distillation.

It is hard to see what influence humidity would have on the transfer of air-borne microorganisms, but it is claimed by some that in the high humidity type of refrigerator, any microorganisms coming in contact with the moist walls will stick there while much of the volatile flavor and odor producing substances in the air are also removed by being dissolved in this same water.

The present findings were contrary to the above statement. It was found that the opening of the refrigerator door was the factor determining the air-borne contamination in the storage compartment, rather than humidity or air movement.

Considerable air from the room enters a refrigerator when the door is opened and it is probable that many microorganisms are carried in in this way. The jar, caused by closing the refrigerator doors may also conceivably break loose small particles of dust or food from the shelves, which could have caused contamination by falling into the exposed plates.

SUMMARY

A study has been made of (a) the operation of an electric refrigerator, (b) the storage of eggs in domestic refrigerators, (c) left-over food storage, (d) frozen-food storage and (e) the odor transfer and air-borne contamination in both the high humidity and standard types of refrigerators.

1. The average operating temperature of a mechanical refrigerator was found to be several degrees above the theoretical setting, while the operating costs are greatly increased by lowering this temperature only a few degrees.

2. Eggs can be safely stored at least a month without serious loss in quality. The preferable method is to use covered containers.

3. Left-over foods are preserved best by storing in covered containers, in which they will keep in good condition for at least four days.

4. The loss of vitamin C in fresh and cooked left-overs, at any one temperature, is inversely proportional to the humidity at which they are stored.

5. A considerable amount of the vitamin C content of left-over foods is lost during refrigeration, most of which is lost during the first day of storage.

6. The defrosting of frozen foods at high or low temperatures causes appreciable losses of vitamin C.

7. Storage of frozen foods in the domestic refrigerator for short periods should be at 16°F. or lower, in order to prevent losses of vitamin C.

8. The amount of flavor transfer is inversely proportional to the storage humidity and the rate of air movement and is not entirely prevented by ordinary glass or oiled-silk covers; sealed jars being the only absolute protection.

9. Any type of dish cover reduces the amount of flavor transfer; however, oiled-silk covers are very inefficient in this respect.

10. The amount of air-borne contamination occurring in a refrigerator appeared to depend more on the door openings than on the humidity or rate of air movement inside the box.

Conclusions

With proper use an efficient refrigerator reduces danger of the development of food poisoning organisms to a minimum as well as preserves the quality and vitamin content of foods better than any other known method.

Storage of fresh and left-over vegetables and fruits at high humidities, preferably in covered containers, best preserves their quality and nutritive value, while meats keep best when loosely wrapped.

Frozen foods can be kept in the freezing compartment for several days without deterioration of quality, but there is some loss of vitamin C.

One objectionable feature met with in home refrigeration is transference of taste from one food to another. However, by using the proper methods of storage, this contamination can be eliminated.

From the standpoint of health, economy and convenience it must be concluded that the modern refrigerator is of inestimable value.

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Approved by:

William B. Esselen Jr.

Ernest M. Parrott

Mary E. Garvey

Graduate Committee

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